8272

MCR-73-235

Contract NAS8-29675

58

Volume 5.0

Systems

September 1973

Selected Option Data Dump

Appendix A Supporting Research and Technology

Space Tug Systems Study (Storable)

(NASA-CR-161899) SPACE TUG SYSTEMS STUDY (STORABLE): SELECTED OPTION DATA DUMP. VOLUME 5.0 SYSTEMS, APPENDIX A: SUPPORTING RESEARCH AND TECHNOLOGY (Martin Marietta Corp.) 272 p

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Presented to;
George C. Marshall
Space Flight Center

MARTIN MARIETTA

MCR-73-235
Contract NAS8-29675

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Volume 5.0 Systems September 1973

Selected Option Data Dump

Appendix A
Supporting Research and Technology

Space Tug Systems Study (Storable)

Presented to;
George C. Marshall
Space Flight Center

MARTIN MARIETTA

VOLUME 5.0

APPENDICES

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APPENDIX A

SUPPORTING RESEARCH & TECHNOLOGY (SRT)

FOR

TUG

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1.0 INTRODUCTION

We have defined a $16 million program of Supporting Research and Technology (SRT) designed to minimize risk and maximize confidence in developing a space transportation system that meets the performance, cost and schedule goals established during this study contract.

All TUG technology requirements were carefully examined and studied by our study team technical staff with full support of technology specialists from the R&D department. The SRT element of low-cost, low-risk hardware development to meet the requirements of the TUG system concerned during this study was identified by this team of technical experts.

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2.0 TUG SRT SUMMARY

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TUG SRT SUMMARY

TASK NO	TASK TITLE	REQUIRED FOR OPTION 1 (79)	1 (—)	2 (83)	2 (—)	3 (79)	3 (83)	3A (79)	3A (83)	EST COST ($K)	SCHEDULE (MONTHS)
	PROPULSION ($5.234 M MAXIMUM)										
	MAIN PROPULSION SYSTEM (MPS)										
P-1	LONG LIFE TURBO PUMP ASSY	X		X		X		X		1000	15
P-2	DEMO OF ENG RESTART CAPABILITY WITH MISSION DUTY CYCLE	X		X		X		X		1500	18
P-3	HIGH AREA RATIO NOZZLE PERFORMANCE			X			X		X	1000	12
P-4	ENGINE LIFE, MAINTENANCE & REFURBISHMENT	X		X		X		X		200	8
P-5	EVAL OF INSPECTION, CLEANING, MAINT FOR PROP MGMT DEVICE	X		X		X		X		49	12
P-6	PROPELLANT MGMT DEVICE EVAL	X		X		X		X		21	4
P-7	EVAL OF PROPELLANT UTILIZATION	X		X		X		X		49	8
P-8	PROPELLANT DUMP TECHNOLOGY	X		X		X		X		128	12
P-9	PROPELLANT COMPATIBILITY & CORROSION	X		X		X		X		180	16
P-10	EFFECTS OF ENGINE EXHAUST ON SPACECRAFT	X		X		X		X		237	16
P-11	FAB TECHNOLOGY FOR TUG PROPELLANT MGMT DEVICES	X		X		X		X		271	10
	ATTITUDE CONTROL PROPULSION SYSTEM (ACPS)										
P-12	HYDRAZINE THRUSTER LIFE & REUSE DEMO PROGRAM	X		X		X		X		400	12
P-13	N_2H_4 PROPELLANT COMPATIBILITY & CORROSION	X		X		X		X		132	15
P-14	EVAL OF INSPECTION, CLEANING, MAINT FOR PROP MGMT DEVICE	X		X		X		X		50	8
P-15	PROPELLANT MGMT DEVICE EVAL	X		X		X		X		17	4
	AVIONICS ($6.474 M MAXIMUM)										
	RENDEZVOUS & DOCKING										
A-1	REMOTE MANNED AND AUTONOMOUS DOCKING			X			X		X	1070	16
A-2	DOCKING STRATEGIES ASSESSMENT			X			X		X	815	36
A-3	PROPELLANT SLOSH EFFECTS IN LOW-G ENVIRONMENT	X		X		X		X		257	18
A-4	R.F. TARGET SIGNATURES			X			X		X	220	15
A-5	SLR RECEIVER APPLICATION AS A STAR TRACKER			X			X		X	194	12
	GUIDANCE & NAVIGATION										
A-6	TERMINAL-PHASE RENDEZVOUS NAVIGATION AND GUIDANCE			X			X		X	257	24
A-7	STRATEGY ASSESSMENT FOR HIGH-VOLUME TUG OPERATIONS	X		X			X		X	475	24
A-8	TARGET VEHICLE SIGNATURES AS STAR TRACKER TARGETS			X			X		X	96	12

Fold out #1

A-9	AUTONOMOUS NAVIGATION TECHNOLOGY FOR SPACE TUG	X		X			X		X	106	12
A-10	INERTIAL MEASUREMENT UNITS EVAL & SELECTION	X		X		X		X		1055	13
	COMMUNICATIONS & DATA MGMT										
A-11	PLANAR ARRAY ANTENNA	X		X		X		X		99	12
A-12	ONE-WAY DOPPLER AND EMERGENCY COMMAND RECEIVER	X		X		X		X		242	15
A-13	FLEXIBLE SIGNAL INTERFACE	X		X		X		X		466	18
	ELECTRICAL POWER										
A-14	DESIGN OF ROLL-UP SOLAR ARRAY SYSTEM			X		X		X		395	16
A-15	"BLUE" SOLAR CELL EVALUATION			X		X		X		42	6
A-16	BATTERY DEVELOPMENT & EVALUATION	X		X		X		X		170	18
A-17	MULTIPLEXED POWER DIST CONTROL & MONITORING SYS DEVEL	X		X		X		X		260	12
A-18	ELECTRO-MECHANICAL UMBILICAL CONNECTION SYSTEM	X		X		X		X		255	14
	STRUCTURES ($2.556 M MAXIMUM)										
S-1	COMPOSITE MATERIAL CHARACTERIZATION	X		X		X		X		169	18
S-2	COMPOSITE JOINT STUDY	X		X		X		X		82	12
S-3	FAILURE ANALYSIS FOR COMPOSITE STRUCTURES	X		X		X		X		264	18
S-4	FINITE ELEMENTS FOR COMPOSITE STRUCTURES	X		X		X		X		316	18
S-5	COMPOSITE HONEYCOMB ASSURANCE	X		X		X		X		150	14
S-6	HONEYCOMB CORE OPTIMIZATION	X		X		X		X		66	9
S-7	LIGHTWEIGHT SHELL STRUCTURES	X		X		X		X		392	22
S-8	FRACTURE TOUGHNESS INVESTIG OF THIN GAGE TITANIUM 6A1-4V	X		X		X		X		240	18
S-9	COMPOSITE HELIUM PRESSURIZATION VESSEL	X		X		X		X		73	9
S-10	CRACK DETECTION SENSITIV FOR THIN GAGE LINERS & JOINTS	X		X		X		X		105	18
S-11	ANALYTICAL METHODS FOR COMPOSITE PRESSURE VESSELS	X		X		X		X		211	18
S-12	LINER BONDING FOR HELIUM PRESSURIZATION VESSEL	X		X		X		X		52	11
S-13	LINER MANUFACTURING FOR THE HELIUM PRESSURIZATION VESSEL	X		X		X		X		66	8
S-14	COMPOSITE OVERWRAPPED TANK ASSURANCE	X		X		X		X		158	11
S-15	PROPELLANT BEHAVIOR IN ELASTIC TANKS	X		X		X		X		85	16
S-16	DOCKING AND CAPTURE OF ELASTIC SPINNING SATELLITES			X			X		X	127	16
	FLIGHT OPERATIONS ($1.268 M MAXIMUM)										
F-1	OPERABILITY ANALYSIS	X		X		X		X		1268	18
	THERMAL ($.656 M MAXIMUM)										
T-1	REUSABILITY OF MULTILAYER INSULATION	X		X		X		X		323	18
T-2	REUSABILITY OF TUG COATINGS	X		X		X		X		333	18
	MANUFACTURING ($.373 M MAXIMUM)										
M-1	IMPROVED WELD TECHNOLOGY - DOMES & BARRELS	X		X		X		X		74	18
M-2	COMPOSITE STRUCTURE DEVELOPMENT	X		X		X		X		86	18
M-3	ONE-PIECE DOME FABRICATION - 2219 AL & 6-4 TI							X		159	18
M-4	SCREEN SURFACE TENSION DEVICE - TANK	X		X		X		X		54	18
	TOTAL - OPTION 1 - 1979 IOC									12186	
	OPTION 2 - 1983 IOC									16402	
	OPTION 3 - 1979 IOC									12042	
	- 1983 IOC									4360	
	OPTION 3A- 1979 IOC									12201	
	- 1983 IOC									4360	

TABLE A-1 OPTIONS 1, 2, 3 AND 3A - TUG SRT SUMMARY COST AND SCHEDULE

FOLD OUT #2

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3.0 TUG SRT SCHEDULES

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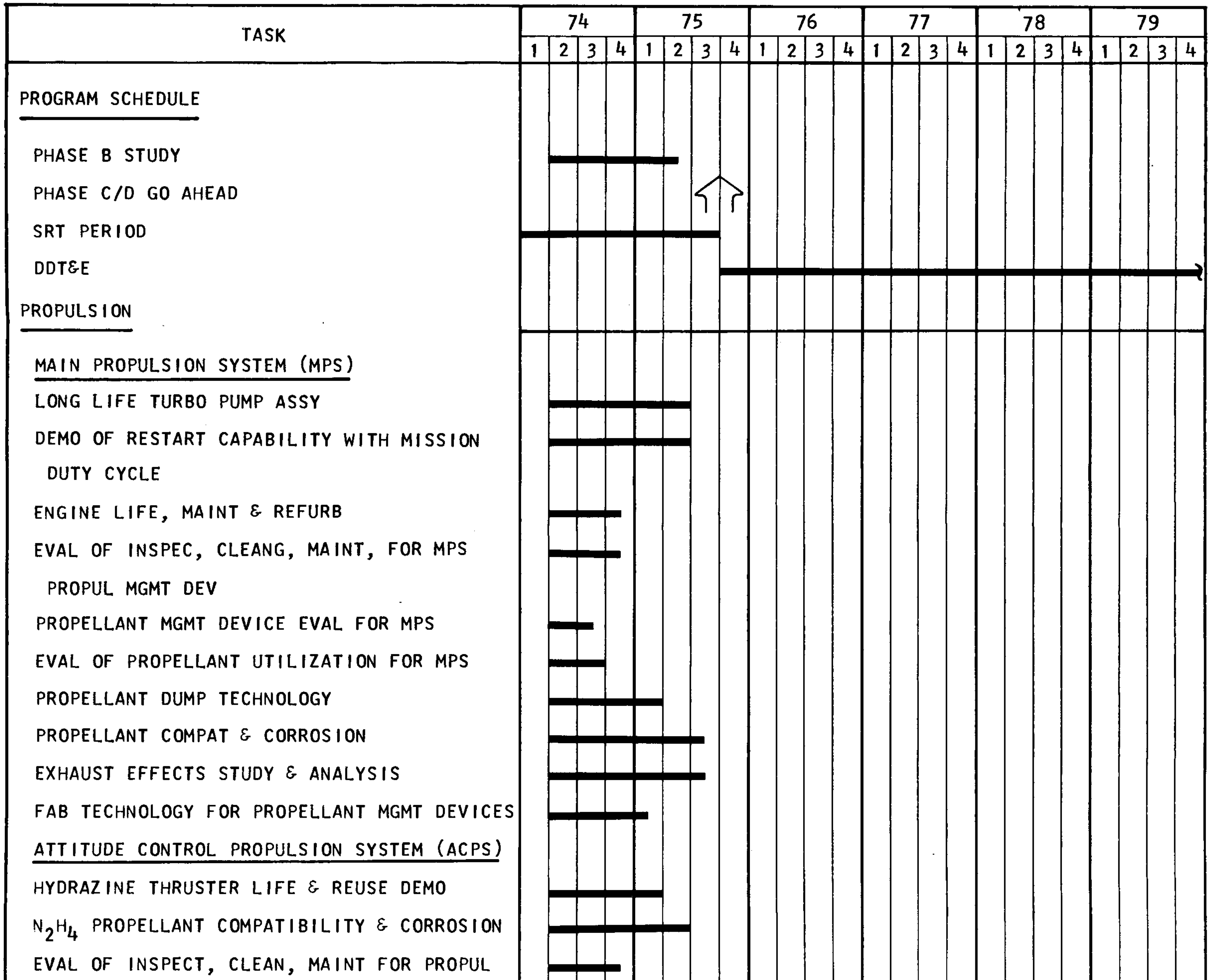
6

TUG SRT SCHEDULE

PROGRAM OPTION NO. 1

CONFIGURATION 1A3-2



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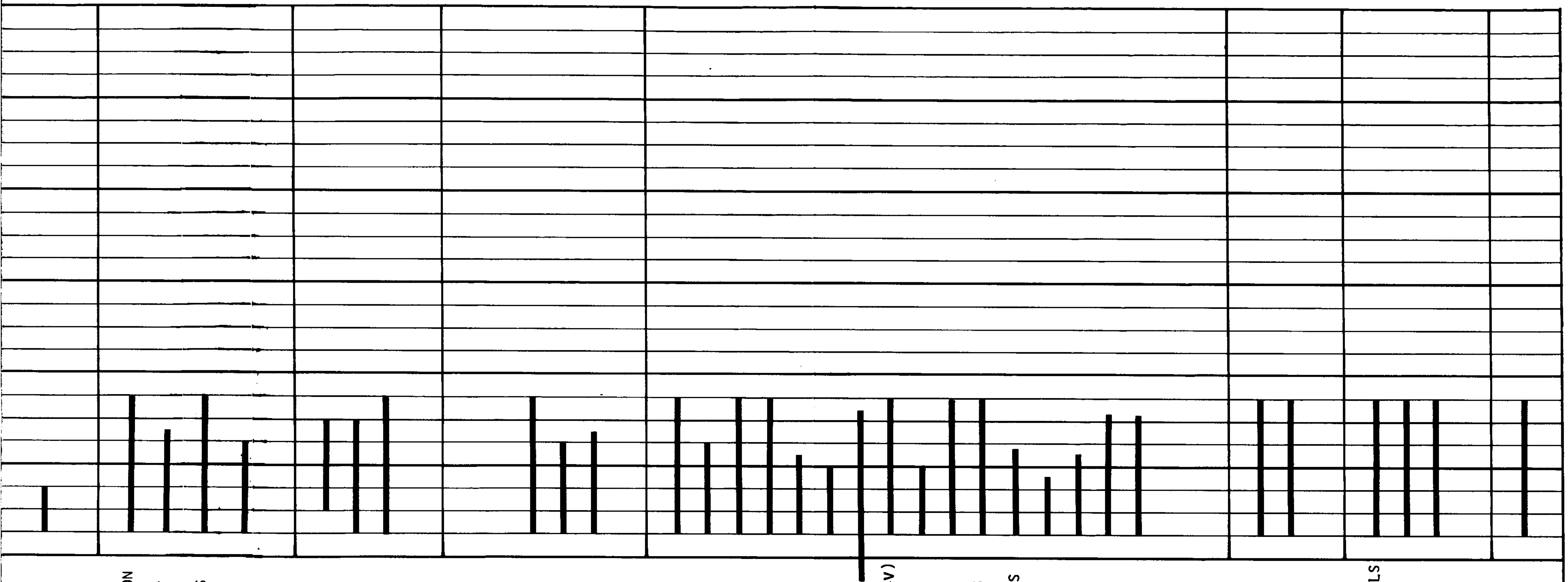


MGMT DEVICE
- PROPELLANT MGMT DEVICE EVAL

AVIONICS
- PROPELLANT SLOSH EFFECTS IN LOW-G ENVIRON
- INERTIAL MEASUREMENT UNITS EVAL & SELECT
- STRATEGY ASSESSMENT FOR HIGH-VOL TUG OPS
- AUTONOMOUS NAV TECHNOLOGY FOR TUG

COMMUNICATIONS & DATA MGMT
- PLANAR ARRAY ANTENNA
- ONE-WAY DOPPLER & EMERG COMMAND RECEIVER
- FLEXIBLE SIGNAL INTERFACE

ELECTRICAL POWER
- BATTERY DEVEL & EVAL
- MULTIPLEXED POWER DIST CONTROL & MON
- ELECTRO-MECHANICAL UMBILICAL CONNECTION

STRUCTURES
- COMPOSITE MATERIAL CHARACTERIZATION
- COMPOSITE JOINT STUDY
- FAILURE ANALYSIS FOR COMPOSITE STR
- FINITE ELEMENTS FOR COMPOSITE STR
- COMPOSITE HONEYCOMB ASSURANCE
- HONEYCOMB CORE OPTIMIZATION
- LIGHTWEIGHT SHELL STR
- FRACTURE TOUGHNESS OF THIN-GAGE TI(6A1-4V)
- COMPOSITE HELIUM PRESSURIZATION VESSEL
- CRACK DETECTION SENSITIVITIES
- ANAL METHODS FOR COMPOSITE PRESS VESSELS
- LINER BONDING FOR HELIUM PRESSURE VESSELS
- LINER MFGR'G FOR HELIUM PRESSURE VESSELS
- COMPOSITE OVERWRAPPED TANK ASSURANCE
- PROPELLANT BEHAVIOR IN ELASTIC TANKS
- DOCKING & CAPTURE OF ELASTIC SPINNING SATELLITE

THERMAL CONTROL
- REUSABILITY OF MULTILAYER INSULATION
- REUSABILITY OF TUG COATINGS

MANUFACTURING
- IMPROVED WELD TECHNOLOGY - DOMES & BARRELS
- COMPOSITE STRUCTURE DEVELOPMENT
- SCREEN SURFACE TENSION DEVICE-TANK

FLIGHT OPERATIONS
- OPERABILITY ANALYSIS

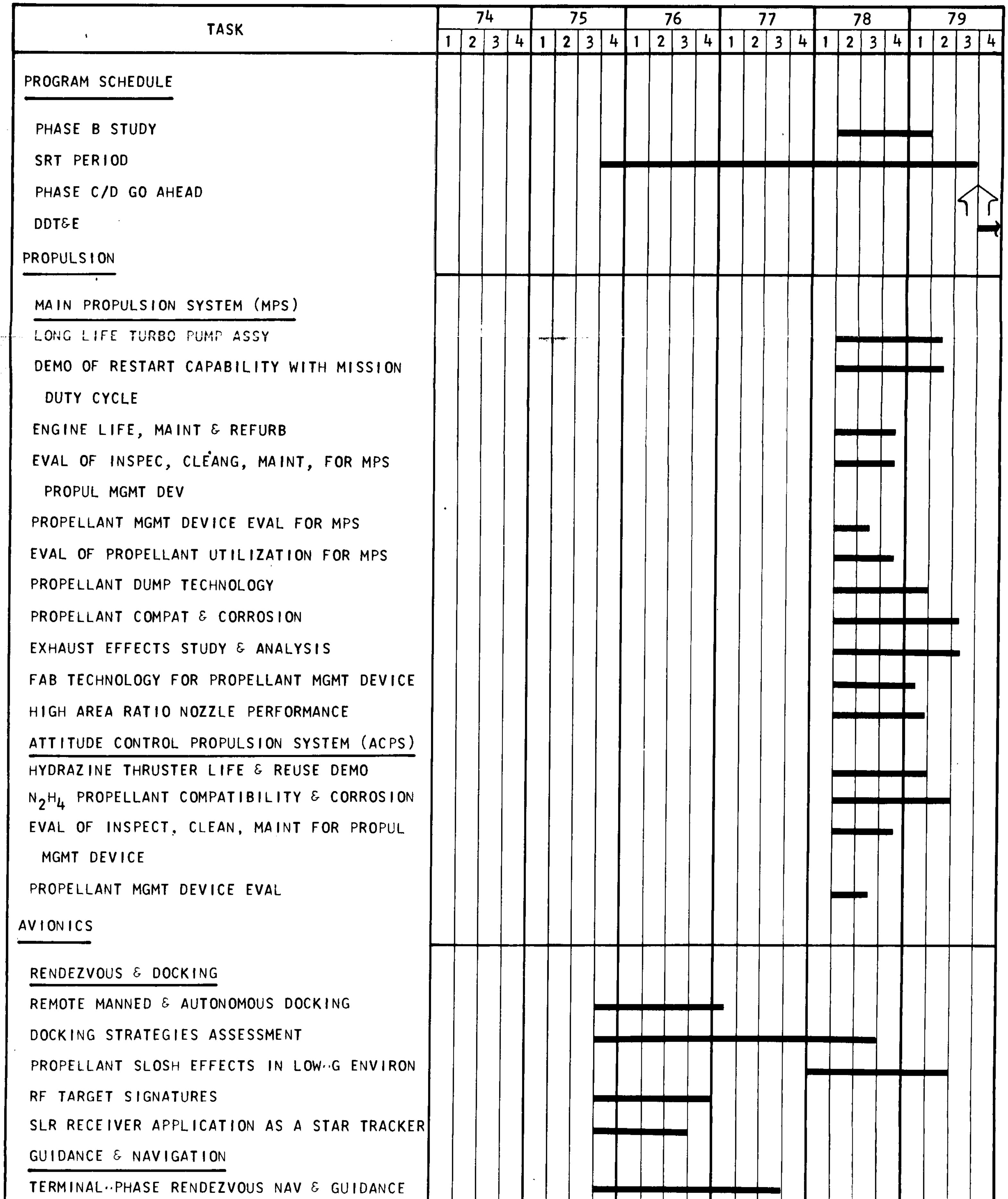
FOLDOUT #2

TABLE A2 OPTION 1 TUG SRT SCHEDULE

TUG SRT SCHEDULE

PROGRAM OPTION NO. 2

CONFIGURATION IA2-4,3



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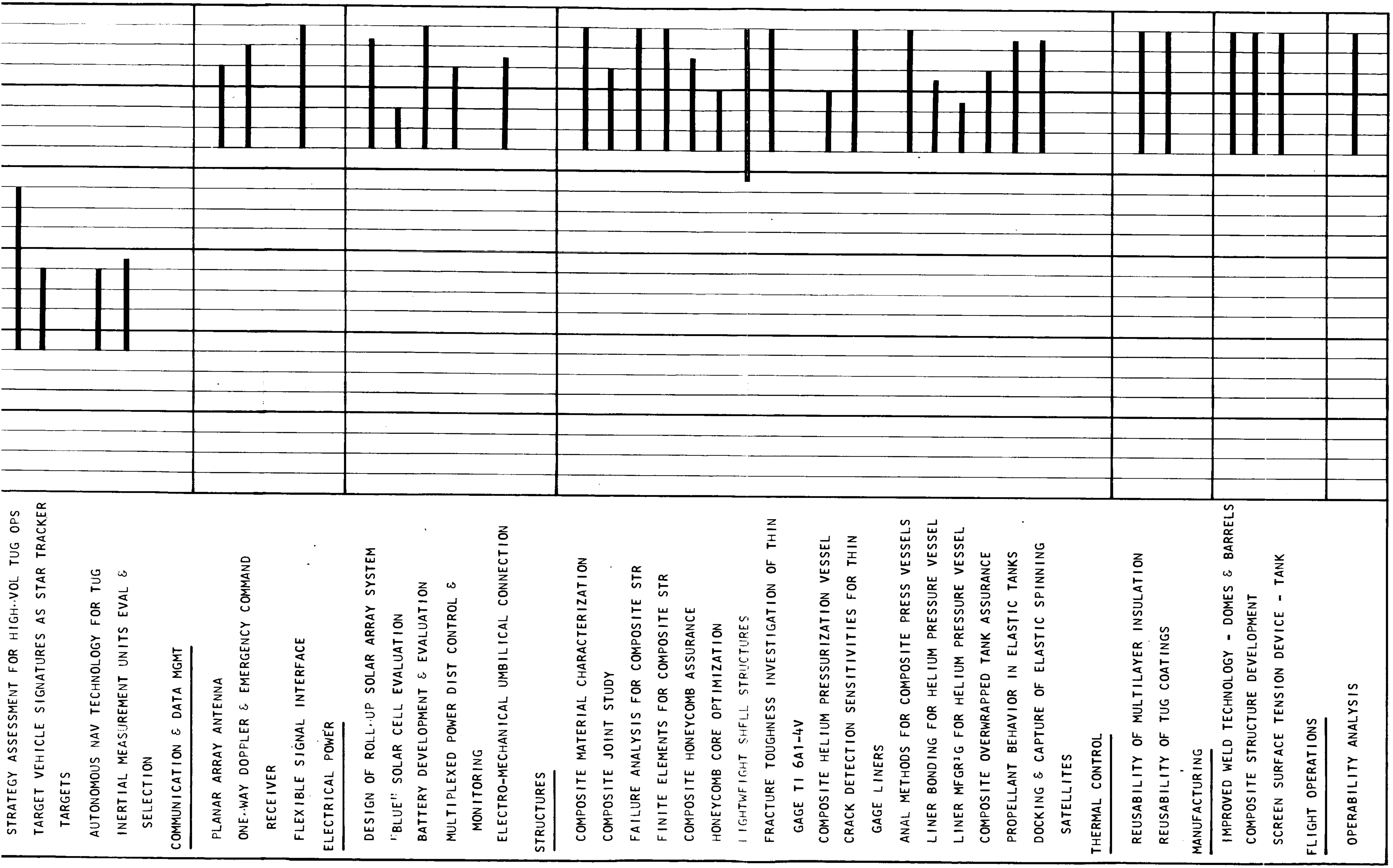


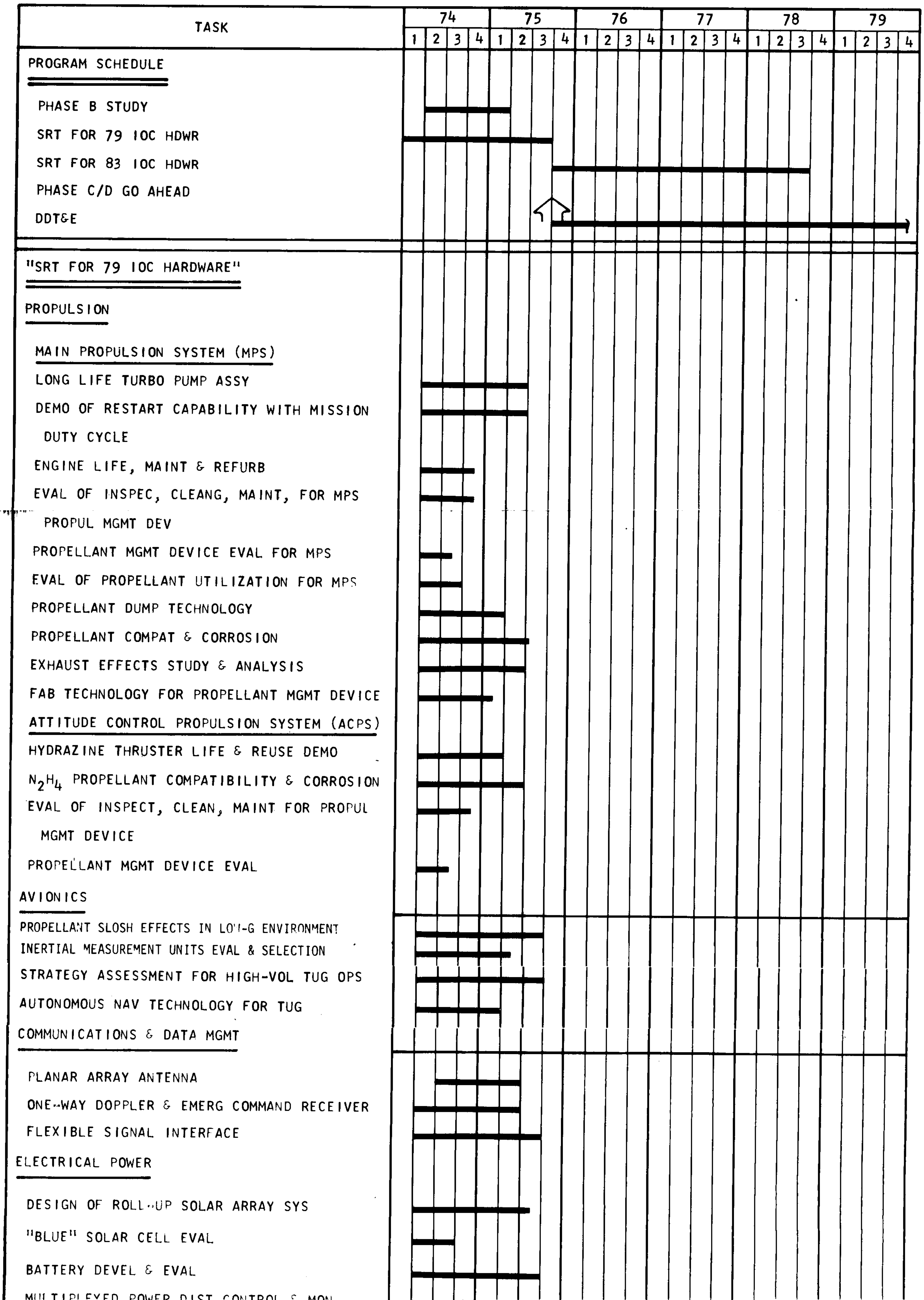
FOLD OUT #2

TABLE A-3 OPTION 2 TUG SRT SCHEDULE

TUG SRT SCHEDULE

PROGRAM OPTION NOS 3 & 3A

CONFIGURATIONS (IA2-8, IA2-4,3) & (IVG-1/-3,2)



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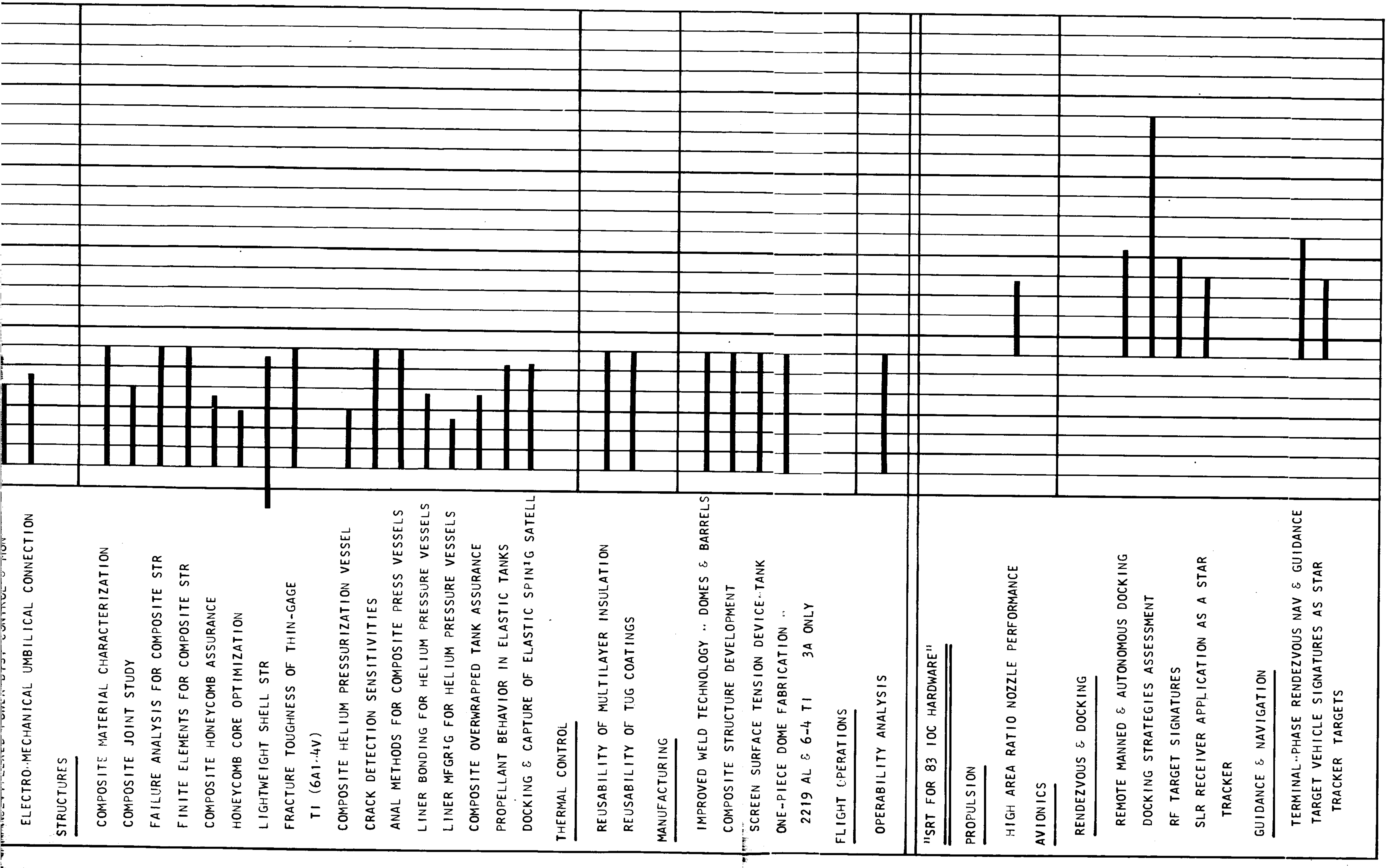

TABLE A-4 OPTION 3 AND 3A TUG SRT SCHEDULE

FOLD OUT #2

2 3

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APPENDIX A

4.1 PROPULSION

P-1 thru P-16

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Main Engine (GFE)

(Information from Joe Mellish ALRC Tug Study Manager)

Task Title: Long Life Turbo Pump Assembly SRT No. P-1

This program would evaluate long life effects on the TPA in such areas as bearings and seals. Hardware would be built and tested.

Duration: 15 months
Cost: $1.0 M

Task Title: Demonstration of Engine Restart Capability with Mission Duty Cycle SRT No. P-2

Engine hardware would be built and tested to evaluate items such as heat soak back after main engine burn, cold orbit soak, hot orbit soak, etc.

Duration: 18 months
Cost: $1.5 M

Task Title: High Area Ratio Nozzle Performance SRT No. P-3

The program would involve the testing of high area ratio nozzles in the size and thrust level required for Tug to verify performance.

Duration: 12 months
Cost: $1.0 M

Task Title: Engine Life, Maintenance, and Refurbishment SRT No. P-4

Study and evaluate the effect of long life, maintenance, and refurbishment on engine design and performance.

Duration: 8 months
Cost: $200 K

/s/ W. E. Pipes III
W. E. Pipes
Dept. 1663, Ext. 3511

Approved: /s/ R. VandeKoppel
R. VandeKoppel
Dept. Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Main Propulsion System SRT No. P-5

Task Title: Evaluation of Inspection, Cleaning and Maintenance Procedures for Space Tug MPS Propellant Management Device

Statement of Problem: The Space Tug is to be a highly maneuverable, reusable spacecraft which has a long service life of up to 10 years. The reusability requirements emphasize the need for all subsystems to be easily inspected and to be as maintenance free as possible.

The MPS Propellant management device (PMD) which utilizes fine mesh screens must be capable of meeting these requirements. The baselined PMD is a trap type device which can be removed to be inspected and cleaned after periodic usage. Because of the fine mesh screens, plugging of the PMD is a potential problem. Any reduction in flow area due to plugging could degrade the performance of the PMD. Procedures for cleaning any contaminated device must be established. Also, techniques for verifying the integrity of the PMD screens must be developed.

Objective: The objective of this task is to establish inspection, maintenance, and cleaning procedures for the MPS propellant management device.

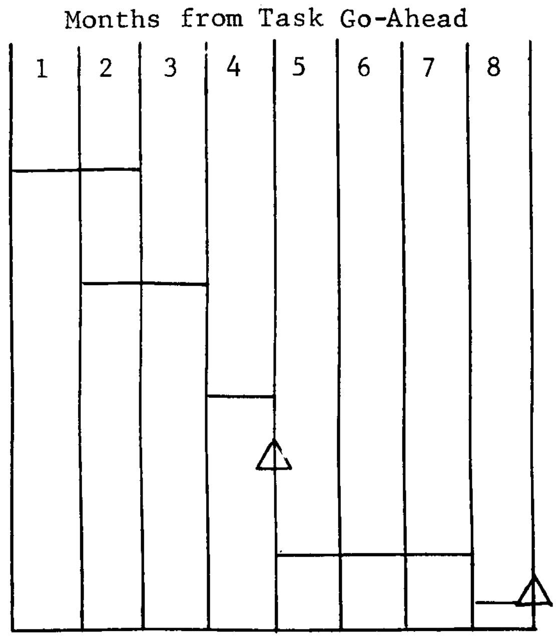
Approach: After the PMD design has been established, a preliminary evaluation of the inspection, maintenance and cleaning requirements and procedures will be conducted. Information will be compiled on cleaning and acceptance procedures used on operation vehicles such as Apollo, Transtage, Agena, etc., keeping in mind that these vehicles are not reusable. The preliminary procedures will be modified as required to take advantage of existing hardware, techniques and procedures developed under previous programs. The finalized procedures will then be verified through ground tests using the prototype PMD which will be built under a related fabrication technology task.

The ground tests will include flow tests that will establish that the PMD screens have not been clogged or damaged in any way. The tests will measure pressure drop versus flowrate for an acceptable, clean PMD and any deviation from the accepted curves would indicate contaminated or damaged screens. Procedures for cleaning and handling the PMD screens will be verified. Also, procedures for minus 1g outflow tests and screen bubble point tests will be verified and incorporated into a flight-readiness manual.

Schedule:

Task Milestones

1. PMD Design Complete
2. Preliminary Evaluation of Procedures for Inspection, Maintenance and Cleaning
3. Review and Compile Related Information from Previous Programs
4. Preferred Procedures Selected
5. Prototype PMD Ready for Test
6. Ground Test Program
7. Final Report



Budget: Manpower - 12 manmonths
Material & Hardware - $1K

Facilities: Engineering Propulsion Laboratory

/s/ G. Robert Dage
G. Robert Dage
Dept. 1662, Ext. 3809

Approved: /s/ R. W. VandeKoppel
R. W. VandeKoppel
Manager
Propulsion ER&D

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Main Propulsion System (MPS) SRT No. P-6

Task Title: Propellant Management Device Evaluation for Space Tug MPS

Statement of Problem: A surface tension device has been selected as the propellant management system for the Space Tug MPS, but very little work has been done to identify the specific type and configuration surface tension device to be used. A device needs to be selected, designed and evaluated with respect to the mission criteria.

Objective: The objective of this task is to select a surface tension device for the fuel and oxidizer tanks of the Space Tug MPS which will satisfy the mission requirements, design the devices and evaluate their performance. Emphasis will be placed on performance, weight and reusability. The design will be carried to the point at which engineering drawings of the devices, showing fabrication details, can be accomplished as part of this task. A development plan detailing the effort required to continue this task through to fabrication of a flight qualified device would be provided. Using these designs, a prototype device will be built and tested under other related Space Tug technology tasks.

Approach: The approach for this task is outlined in the following steps:

1. Collect spacecraft and mission criteria applicable to the design of the surface tension device for the MPS. This effort will be primarily aimed at defining the expected acceleration environment for the entire mission. Other system requirements such as propellant off-loading, emergency dump, etc. will also be established.

2. Various candidate surface tension devices, which appear to be capable of satisfying the mission requirements, will be identified. For this application, trap type devices appear to be the best suited, so the candidates will be various forms of refillable and non-refillable traps. A preliminary evaluation of their capabilities will be accomplished. From this evaluation, the most promising concept will be selected.

3. A detailed analysis of the selected system will be accomplished. Its performance and capabilities will be optimized. The operation of the device throughout the mission will be

evaluated to insure it has adequate design margins. Sizing of the trap reservoir, selection of the screen materials and the configuration of the flow annulus will be the primary areas to be analyzed.

4. Factors such as reusability, modular installation, reliability, loading, handling and compatibility will be evaluated to insure that the device will satisfy the multiple reuse requirements.

5. The structural design and fabrication of the device will be evaluated. The objective will be to provide sufficient structural strength, while minimizing weight. Results from the related fabrication technology task will be implemented. An engineering drawing, showing the fabrication details, will be made.

6. A development plan, presenting the effort necessary to continue the development of the device through to flight qualified hardware, will be written. Any necessary development testing will be identified.

Schedule: 4 months of effort with a final report.

Budget: 5 manmonths, 1 hour computer time.

Facilities: None required.

/s/ G. Robert Page
G. Robert Page
Dept. 1662, Ext. 3809

Approved: /s/ R. W. VandeKoppel
R. W. VandeKoppel
Manager
Propulsion ER&D

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Main Propulsion System SRT No. P-7

Task Title: Evaluation of Propellant Utilization System for Space Tug MPS

Statement of Problem: Controlling propellant residuals in the MPS is considered a critical problem in minimizing weight penalities for Space Tug. In order to minimize propellant residuals, an accurate and reliable propellant utilization (PU) system must be used that includes a propellant quantity gaging system and necessary control electronics. In addition to minimizing residuals, the PU system must be capable of providing the required mixture ratio control during MPS engine operation. Further, the propellant mass gaging system has to accurately measure propellant quantities during loading and outflow.

Objective: The objective of this task is to evaluate and select the preferred PU system for the Space Tug MPS oxidizer and fuel tanks.

Approach: The gaging requirements of the Space Tug will be determined and transposed into hardware requirements of the gaging system. With these requirements in mind an existing literature search will be updated to evaluate recent developments in the state-of-the-art. Vendors of hardware that appear to meet Tug requirements will then be contacted with the objective of visiting those with the most promising hardware for demonstrations.

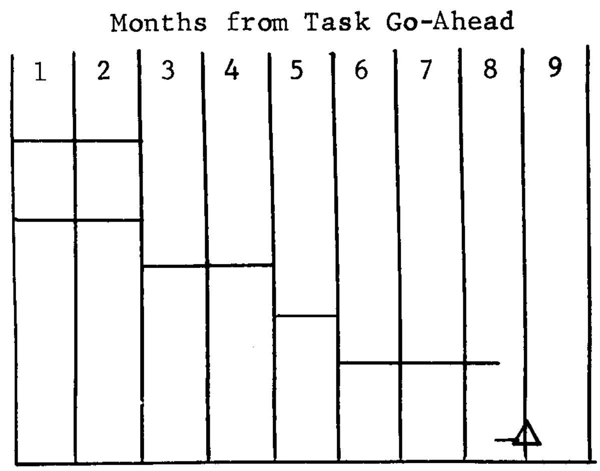
The types of equipment that will be investigated are both point sensors, which may be required for accurate loading and/or updating the output data from a less accurate continuous gaging system, and continuous sensors. Also, systems that give a direct indication of propellant quantity and indirect or inferential systems will be investigated. In addition to gaging systems as such, other methods of meeting the gaging requirements will be investigated such as "inventory keeping" wherein the total quantity of propellant expelled is determined by integrating flowmeter output, or other means, so that the propellant remaining can be calculated.

It is felt that the various vendors have sufficient development results and data available to allow the selection of the preferred system. Following this selection, two prototype systems for the oxidizer and fuel tanks would be obtained for verification and acceptante tests.

Schedule:

Task Milestones

1. Identify Space Tug PU Requirements
2. Literature Search Update
3. Vendor Contacts
4. Vendor Hardware Evaluation
5. Final Evaluation and Selection
6. Final Report



Budget: Manpower - 12 manmonths
Trips - 4 trips/2 men/ 2 days each

Facilities: None

/s/ G. Robert Page
G. Robert Page
Dept. 1662, Ext. 3809

Approved: /s/ R. W. VandeKoppel
R. W. VandeKoppel
Manager
Propulsion ER&D

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Propulsion (Main) SRT No. P-8

Task Title: Propellant Dump Technology

Statement of Problem: In order to assure that Tug will be capable of successfully dumping its residual main tank propellants prior to returning to the orbiter cargo compartment or during orbiter descent, several preliminary tasks are warranted.

The primary goal of a successful propellant dump must be to prevent any propellant from contacting surfaces of Tug or of the orbiter. Any propellant so deposited is a source of potential chemical attack, or of hypergolic reaction should both propellants be present. Hypergolic reaction in the vicinity of the Tug or orbiter is also a potential hazard. The factors which influence deposition and dispersion should be analyzed, and orderly design criteria established through the development of models and preliminary test activity in order that the proper factors may be integrated into Tug design from the outset.

Objective: To develop technology to assure that Tug design may incorporate propellant dump capabilities during its mission profile without jeopardizing Tug or orbiter effectiveness, reliability, reuseability or safety.

Approach: Task I - Develop or modify a computer model to predict dispersion patterns of propellant vents, based on specific propellants and vent exit conditions (temperature, pressure, direction, velocity, rotational energy, solar energy, vent time, altitude).

Task II - Determine the probability of electrostatic influence on dispersal pattern due to the venting commodity exhibiting electron loss. If it is determined that this is a significant item, particularly under orbit conditions, it must be incorporated into model of Task I.

Task III - Using Task I results, perform conceptual and sketch design of a nonpropulsive vent which incorporates all desirable characteristics.

Task IV - Build and test a scale model of the vent resulting from Task III.

Task V - Experimentally determine the effects of residual propellants and reaction products on candidate Tug and orbiter surface materials when exposed to vacuum conditions.

Task VI - Need for propellant dump creates a criteria for propellant management screens. Assure that criterion is input.

Schedule: Approximately 12 months.

Budget: Labor = 30 mm
Material = $5K
Computer Time = 5 hours, CDC 6400

Facilities: None

/s/ B. Chall
B. Chall
Dept. 1664, Ext. 3346

/s/ R. W. VandeKoppel
R. W. VandeKoppel
Manager
Propulsion ER&D

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Propulsion (Main) SRT No. P-9

Task Title: Propellant Compatibility and Corrosion

Statement of Problem: Data is available on short term compatibility of the three propellants - hydrazine, monomethylhydrazine, and nitrogen tetroxide, with a number of propulsion system construction materials and for long term static storage of nitrogen tetroxide in Titan II tankage materials. This data will be useful in selection of Tug construction materials but once these materials are selected they must be subjected to long term compatibility testing. Special emphasis must be placed on testing bimetallic joints proposed for use on Tug because the electrochemical corrosion induced by these joints is often sufficiently slow that no problem is observed in missions of short duration but on long duration missions and with reuse the slow acting corrosion can weaken parts to failure.

Special attention must be directed at problems arising from reuse. All three propellants absorb moisture from the air increasing their corrosion potential. The hydrazine fuels also absorb carbon dioxide to produce a very corrosive substance, carbazic acid. Investigations of the effects of exposure of a system containing post-use residual propellant to air will be required. These will involve examination of the potential of air exposure in causing harmful corrosion to structural components and the nature and quantity of sludge-like deposits produced.

This compatibility testing should also be directed toward an examination of the consequences of propellant contact with the exterior surfaces of propulsion hardware since multiple reuse greatly increases the change of spillage during refueling. This will include propellant in ambient air contact effect on composite materials such as glass, boron, graphite or PRD 49 filaments bound by epoxies, polyesters, polyimides, etc.

Objective: The objective will be to provide data suitable for selection of the best possible materials for use in construction of the Space Tug. This will include test data on materials used in direct contact with the three propellants, bimetallic joints required and the effects of air contamination on these materials when wet with propellants. Data will also be generated regarding the combined synergistic effect of air and propellants on the exterior surfaces of propulsion system components.

Approach:

1. Tankage materials and joints will be immersed in the appropriate propellant and test articles tested for the following:

   A. Fuels

      1) propellant decomposition;
      2) propellant contamination;
      3) material corrosion;
      4) sludge buildup;
      5) effects of air exposure; and
      6) special cleaning procedures.

   B. Oxidizer

      1) corrosion of materials;
      2) contamination of propellants;
      3) sludge buildup;
      4) effects of air exposure; and
      5) special cleaning procedures.

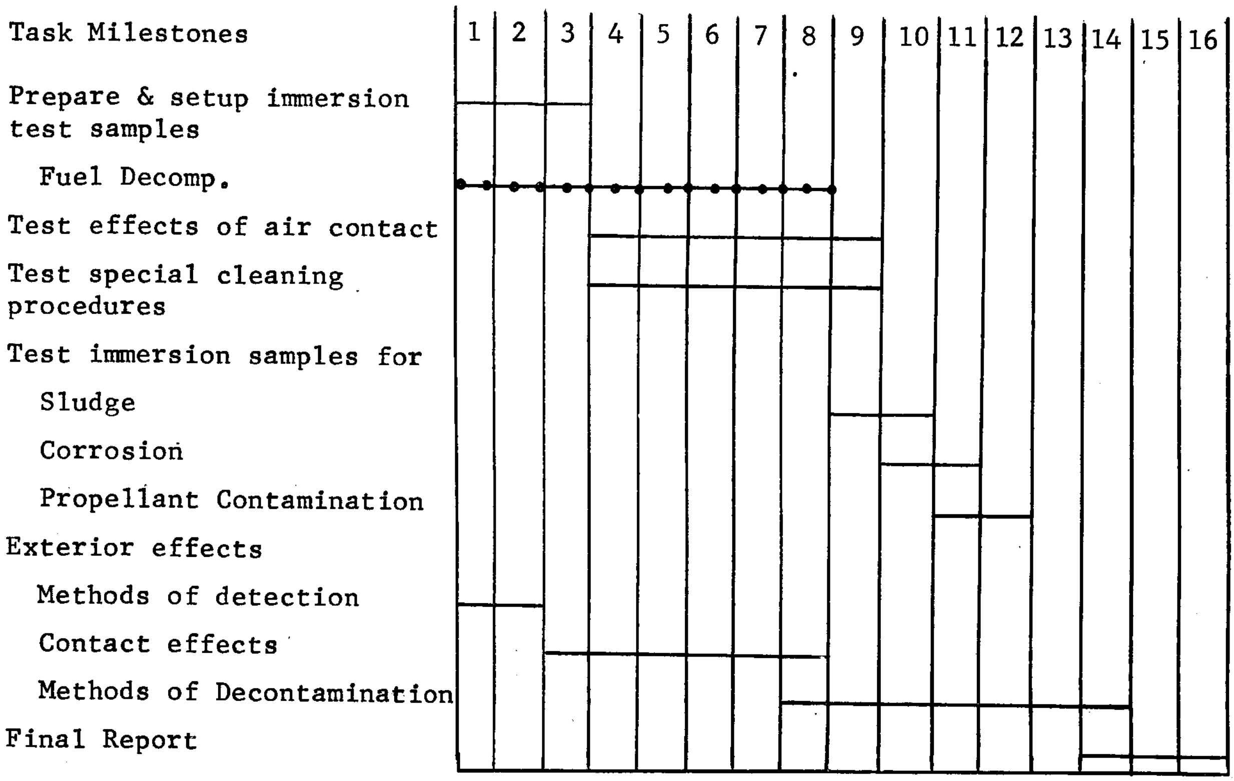
2. Exterior surfaces will be subjected to exposure to propellant in the presence of moist air and test articles tested for the following:

   A. Effect of contact and contact time on surface finish, strength, and flexibility.

   B. Methods of detection of these effects.

   C. Methods of decontamination of surfaces and their effects.

<u>Schedule</u>:



<u>Budget</u>: Total program 15 months, 45 manmonths (Unburdened)

8	test engineers (immersion)
6	analytical chemists
8	test engines (exterior exposure)
6	materials scientists
28	
17	technicians
45	manmonths

<u>Facilities</u>: Propulsion Engineering Laboratory; Propulsion Chemistry Laboratory; Materials Testing Laboratory. No new facilities or equipment required.

/s/ L. O. Williams
L. O. Williams
Dept. 1664, Ext. 3829

Approved: /s/ R. W. VandeKoppel
R. W. VandeKoppel
Manager
Propulsion ER&D

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Main Propulsion System SRT No. P-10

Task Title: RCS & Main Engine Payload Exhaust Effects (Tip Off Loads, Heating, Contamination)

Statement of Problem: The compatibility of the spacecraft with the exhaust product of a N_2O_4/MMH engine is of major concern in the design of reusable spacecraft systems and components. Residual contamination of thermal control surfaces, optical surfaces, solar cells, antennas, and composite materials may result in structural or functional degradation that limit the life of the spacecraft.

Contamination of some components may have short term functional degradation effects such as vapor condensation on optical surfaces Other contamination may have permanent effects like degradation of structural materials or changes in emissivity/absorptance of thermal surfaces.

There is no way to soft dock or depart from a spacecraft without directing exhause at the spacecraft.

An OOS service mission clearly states a requirement that we do not perturb the satellite. It makes little sense to design and build a service tug that upon rendezvous, docking and departure damages or degrades the satellites.

Objective: The initial phase of this effort will include a study of: 1) spacecraft materials and components that are apt to be affected by N_2O_4/MMH engine exhause products; 2) engine exhaust products during steady state firing and start up and termination transients; 3) engine exhaust plume expansion for N_2O_4/MMH engines at steady state firing; and 4) establish a test plan for Phase II efforts.

Phase II will provide and subject selected materials to simulated space conditions and engine exhause products. Test data will be analyzed and a report written which will provide a baseline for design of N_2O_4/MMH engine systems and the associated functional components and structure from a contamination point of view.

Phase III involves analysis of operational aspects of contamination control or alleviation. Typically, tasks are to:

1. Prepare criteria that can be used for rendezvous and docking strategy to assure we do not "perturb" the satellite that we are servicing.

2. Prepare design criteria that can be used for system and payload integration to assure solar arrays, antenna, on-board experiments and crew safety are not compromised by engine exhausts.

3. Assist in assembling back-up data concerning exhaust effects for customer presentation.

Approach: Begine with state of the art plume analysis tools (such as the Lockheed series of programs) and:

1. Evaluate Transtage and Tug main engine exhaust flowfield and composition.

2. Make monor modification to the Lockheed PLIMP program to adapt it for contamination assessment. Interface with personnel in the Skylab contamination analysis section for modeling of deposition.

3. Rendezvous and docking often involves complicated maneuvers in which the satellite takes on varied locations and orientation within the exhaust flowfields. Determine if there is a means of coupling the impingement effects calculations into the flight dynamics calculations to assure the firing sequence and orientation of the tug do not significantly perturb payloads. This should help assure meaningful rendezvous and docking software development.

The second phase of this program will be to test candidate materials in a simulated space environment and engine exhaust products. The following is a likely test matrix:

Test	Specimen Location Plume Position		Measurement
Materials Components	Hot	Cold	
A. Thermal Control Surfaces			Absorptance
Coatings			
1 3M Black Velvet	X	X	Emitance
2 Specular Alzak	X	X	Microscopic Stress Level

B. Optical Surfaces			
Camera Lenses			
MgF2	X	X	Transmissibility
Reflective			Reflectance
As_2S_3	X	X	
SiO	X	X	
Metals	X	X	Reflectance
C. Solar Cell	X		Power Output
D. Antenna			RF signal generation
1 Beryllium copper	X	X	Stress level
2 Stainless Steel	X	X	
E. Composites			Microscopic
1 Glass	X	X	Ultimate strength
1 Boron	X	X	Weight change
1 Graphite	X	X	Swell
1 Ceramic	X	X	
F. Structural			
1 Stainless	X	X	Microscopic
1 Aluminum	X	X	Discoloration Ultimate strength Surface hardness

1. Other items will be stressed to levels antitipcated on spacecraft components.

Engine exhaust plume angles will not be tested. All tests will be performed with exhaust products impinging on the test item.

Test data will be analyzed and included in a final report. The conclusions of the report will provide baseline data for the selection of materials and life expectance vs exhaust product contamination level.

Schedule:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Phase I																
a) Matl. Study																
b) Exhaust Products & Characteristics																
c) Test Plan																
Phase II																
a) Procurement																
b) Future Design & Procedure																
c) Fab and Build																
d) Test																
e) Final Report																
Manmonths	2	3	3	3	1½	3	3	4	4	4	4	4	4	4	4	1
Manpower $K																
Material $K	.1	.1	.1	.1	3	6	6		1	1						
Travel $K	.3	.3	.6	.6		.6	.6								.3	.3
Computer Hrs.	3	3	3	3							3	3	2			
TOTAL																

Facilities: The following facilities are located at the Martin Marietta Corporation's Waterton plant and will be utilized to perform this task: Library and General Office Space; Computer; Model Shop; EPL; Failure Analysis Lab; Q.C. Lab.

/s/ Lyle Mason
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Approved: /s/ R. W. VandeKoppel
R. W. VandeKoppel
Manager
Propulsion ER&D

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Main Propulsion System and Attitude Control Propulsion System SRT No. P-11

Task Title: Development of Fabrication Technology for Space Tug Propellant Management Devices

Statement of Problem: This task addresses the problems associated with the fabrication of propellant management devices (PMD) that employ fine mesh screens to provide the retention/expulsion of propellants for the MPS and ACPS during low-g periods. Since the PMD retention/expulsion capability is directly related to the effective pore size of the screens, any pore enlargement or other communication path across the screens which is greater than the designed screen pore size will degrade performance of the PMD. The PMD fabrication techniques, therefore, must be such that they maintain structural integrity of the screen and provide adequate joining of screen to screen or screen to metal.

In order not to degrade the capabilities of the PMD, the specific fabrication problems which are considered to be critical are related to joining, forming, handling, and repairing of the fine mesh screen. Methods for joining screens to either other screens or plate which have been investigated include welding, brazing, metal flame spray, and soldering. Of these methods, welding is the preferred approach and most of the screen welding experience has been with stainless steel. Since titanium and aluminum are candidate tankage materials, capabilities for welding of titanium and aluminum screens must be developed. The PMD design could require that the fine mesh screens be made with compound curvature to closely match the tank interior shape. Forming of screens into compound curvature usually requires stretching of the material which results for forming compound curvature screens must be developed. For use in a reusable system, handling procedures and method for repairing the PMD have to be developed.

Objective: The overall objective of this task is the development of fabrication expertise which will allow Martin Marietta to build the PMDs for the Space Tug MPS and ACPS. Specific objectives will be to develop forming, joining, handling, and repairing processes and procedures for aluminum and titanium.

Approach: Martin Marietta has built several subscale capillary devices which used fine mesh stainless steel screens. Of particular significance was the fabrication of a 70-inch diameter screen liner. The welding techniques which have been developed for stainless steel will be applied to aluminum and titanium screens. In addition, the feasibility of electron beam welding will be evaluated. As backup joining techniques, the brazing and metal flame spray of aluminum and titanium screens will be investigated. The metal flame spray method could be attractive for making repairs on damaged screens.

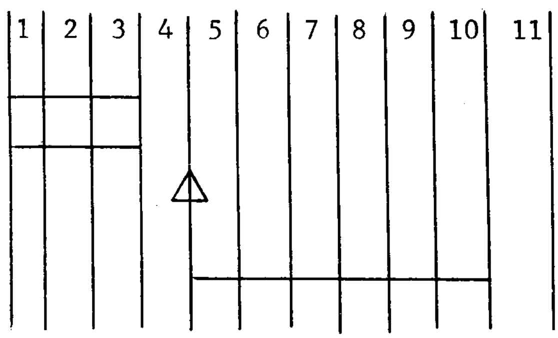
In the limited experience with forming compound curvature screens, the best results have been obtained with pleat forming. The first successful pleat forming operation was accomplished at the AMT facility where a 72-pleat stainless steel hemispherical device of approximately 12 inch diameter was fabricated. Under this task, pleat forming for diameters up to approximately 30 inches will be evaluated for aluminum and titanium screens. Other attractive forming techniques that will be evaluated are spin forming and hot-die forming. The forming investigation will utilize existing dies where possible and the screens will be bubble point tested before and after in order to determine any degradation.

The results from the screen joining and forming investigations will be employed in the two related PMD design tasks. The output from the design tasks will include prototype designs of the ACPS and MPS propellant management systems. Under this task, these two prototype systems will be fabricated. Ground tests will then be conducted to verify the operating and performance characteristics and to evaluate inspection, maintenance, and cleaning procedures for the prototype PMDs. These ground tests will be conducted under two other related technology tasks.

<u>Schedule</u>:

Task Milestones

1. Evaluate Joining Methods
2. Evaluate Forming Methods
3. Complete ACPS & MPS PMD Designs
4. Fabricate Prototype ACPS and MPS PMDs



<u>Budget</u>: Manpower - 64 manmonths
Materials and Hardware - $15K

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Facilities: AMT and LH_2 Laboratory

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/s/ R. W. VandeKoppel
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SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: ACPS Engine SRT No. P-12

Task Title: Hydrazine Thruster Life and Reuse Demonstration Program

Statement of Problem: The reusable aspects of Tug, long life, and refurbishment reflect a change in emphasis from previously designed thrusters. Current technology in this area indicates that steady state and pulsing life can be increased significantly over that of current flight qualified thrusters. For example projections on steady state life are an order of magnitude greater than that on current thrusters. However, these projections are based on limited data.

Current thrusters as well as those projected in the future have the capability of catalyst bed refurbishment. This involves cutting the weld between the chamber and injector, replacing the catalyst and rewelding the assembly. The refurbished engine then has the potential performance and life of a new thruster. When a thruster has been subjected to a number of Tug missions such that its' demonstrated life is achieved, there is a question as to whether or not the thruster should be refurbished. It is possible that the number of thermal cycles and pressure cycles on the basic chamber has reached a point where structural fatigue of the material, and other considerations, may not warrant refurbishment. However, if refurbishment is practical, what is the number of refurbishments and life extension possible. These questions are of particular interest on a new long life thruster which has projected life, based on the initial build, an order of magnitude greater than current flight qualified thrusters.

Approach: Because of the limited data in this area, a hardware program should be initiated to address the specific questions previously mentioned. The program would consist of approximately three development thrusters to be built and tested to the Tug peculiar duty cycle and environment. The thrusters would be built to the level of technology available at that time and tested to investigate potential problem areas as related to long life and refurbishment.

Schedule: 12 months during the Tug Phase B effort.

Budget: The program could be conducted for approximately $400,000 which would include the hardware build, manpower, and materials.

Facilities: This type of program could be conducted at any of the present monopropellant hydrazine thruster manufacturers (Rocket Research, Marquardt, TRW, Hamilton Standard, and Walter Kidde).

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/s/ R. W. VandeKoppel
Manager
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SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Propulsion (ACPS) SRT No. P-13

Task Title: N_2H_4 Propellant Compatibility and Corrosion

Statement of Problem: Data is available on short term compatibility of hydrazine with a number of propulsion system construction materials. This data will be useful in selection of Tug construction materials but once these materials are selected they must be subjected to long term compatibility testing. Special emphasis must be placed on testing bimetallic joints proposed for use on Tug because the electrochemical corrosion induced by these joints is often sufficiently slow that no problem is observed in missions of short duration but on long duration missions and with reuse the slow acting corrosion can weaken parts to failure.

Special attention must be directed at problems arising from reuse. Hydrazine propellant absorbs moisture from the air increasing their corrosion potential. The hydrazine fuels also absorb carbon dioxide to produce a very corrosive substance, carbazic acid. Investigations of the effects of exposure of a system containing post-use residual propellant to air will be required. These will involve examination of the potential of air exposure in causing harmfull corrosion to structural components and the nature and quantity of sludge-like deposits produced.

This compatibility testing should also be directed toward an examination of the consequences of propellant contact with the exterior surfaces of propulsion hardware since multiple reuse greatly increases the chance of spillage during refueling. This will include propellant in ambient air contact effect on composite materials such as glass, baron, graphite or PRD 49 filaments bound by epoxic, polyesters, polyimide, etc.

Objective: The objective will be to provide data suitable for selection of the best possible materials for use in construction of the Space Tug. This will include test data on materials used in direct contact with the hydrazine propellant, bimetallic joints required and the effects of air contamination on these materials when wet with propellant. Data will also be generated regarding the combined synergistic effect of air and propellant on the exterior surfaces of propulsion system components.

Approach:

1. Tankage materials and joints will be emersed in the appropriate propellant and test articles tested for the following:

   a. propellant decomposition;

   b. propellant contamination;

   c. material corrosion;

   d. sludge buildup;

   e. effects of air exposure; and

   f. special cleaning procedures

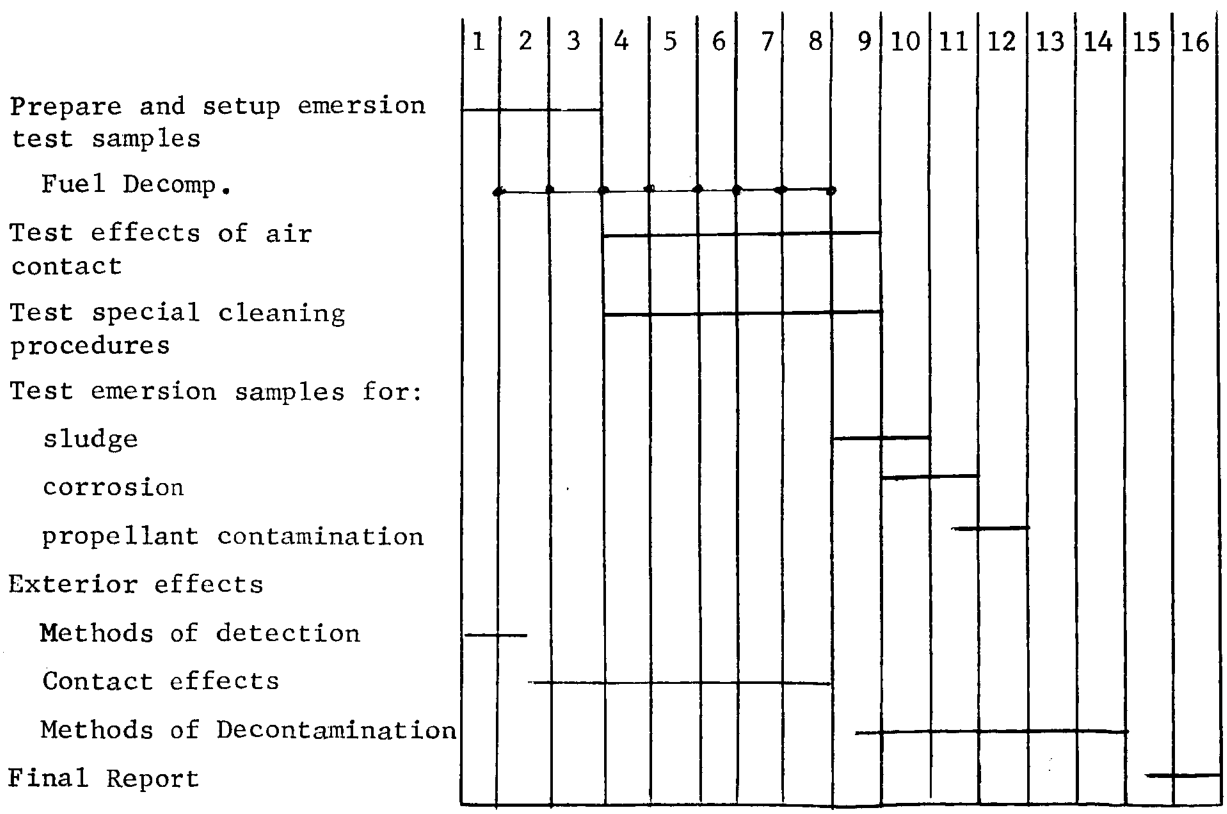
2. Exterior surfaces will be subjected to exposure to propellant vapors and liquid propellant in the presence of moist air and test articles tested for the following:

   a. effect of contact and contact time on surface finish, strength, and flexibility;

   b. methods of detection of these effects; and

   c. methods of decontamination

Schedule:



Budget: (Unburdened)

Total program 15 months, 33 manmonths

6	test engineers (emersion)
5	analytical chemists
6	test engineers (exterior exposure)
4	materials scientists
21	
12	technicians
33	manmonths

Facilities: Propulsion Engineering Laboratory; Propulsion Chemistry Laboratory; Materials Testing Laboratory. No new facilities or equipment required.

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/s/ R. W. VandeKoppel
R. W. VandeKoppel
Manager
Propulsion ER&D

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Attitude Control Propulsion System SRT No. P-14

Task Title: Evaluation of Inspection, Cleaning and Maintenance Procedures for Space Tug ACPS Propellant Management Device

Statement of Problem: The Space Tug is to be a highly maneuverable, reusable spacecraft which has a service life of up to 10 years. The reusability requirements emphasize the need for all subsystems to be easily inspected and to be as maintenance free as possible.

The ACPS propellant management device (PMD) which utilizes fine mesh screens must be capable of meeting these requirements. If the PMD is an integral part of the ACPS tank, it must be capable of being remotely inspected and cleaned. Because of the fine mesh screens, plugging of the PMD is a potential problem. Any reduction in screen flow area due to plugging could degrade the performance of the PMD. Inspection techniques must be established to determine operational status of the PMD. Also, if the PMD does not pass the acceptance check, procedures must be established to identify the problem and return the system to a flight-ready condition.

Objective: The objective of this task is to establish inspection, maintenance, and cleaning procedures for the ACPS propellant management device.

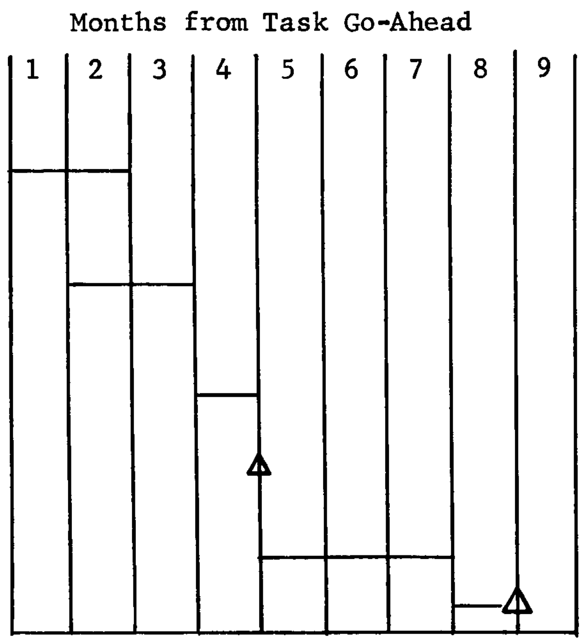
Approach: After the PMD design has been established, a preliminary evaluation of the inspection, maintenance and cleaning requirements and procedures will be conducted. Information will be compiled on cleaning and acceptance test procedures used on operational vehicles such as Apollo, Transtage, Agena, etc., keeping in mind that these vehicles are not reusable. The preliminary procedures will be modified as required to take advantage of existing hardware, techniques and procedures developed under previous programs. The finalized procedures will then be verified through ground tests using the prototype ACPS tank and PMD which will be built under a related fabrication technology task.

The ground tests will include flow tests that will establish that the PMD screens have not been clogged or damaged in any way. The tests will determine the flowrate range for an acceptable, clean PMD and any lower flowrates would indicate contaminated screens. Tests to verify procedures to unplug the screens will be conducted. The ground test program will also verify procedures and techniques for the remote bubble point check of the PMD screens.

<u>Schedule</u>:

Task Milestones

1. PMD Design Complete
2. Preliminary Evaluation of Procedures for Inspection, Maintenance and Cleaning
3. Review and Compile Related Information from Previous Program
4. Preferred Procedures Selected
5. Prototype ACPS Tank and PMD Ready to Test
6. Ground Test Program
7. Final Report



<u>Budget</u>: Manpower - 12 manmonths
Material & Hardware - $2K

<u>Facilities</u>: Engineering Propulsion Laboratory

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/s/ <u>R. W. VandeKoppel</u>
Manager
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SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Attitude Control Propulsion System (ACPS) SRT No. P-15

Task Title: Propellant Management Device Evaluation for Space Tug ACPS

Statement of Problem: A surface tension device has been selected as the propellant management system for the Space Tug ACPS, but very little work has been done to identify the specific type and configuration surface tension device to be used. A device needs to be selected, designed and evaluated with respect to the mission criteria.

Objective: The objective of this task is to select a surface tension device for the ACPS tank of the Space Tug which will satisfy the mission requirements, design the device and evaluate its performance. Emphasis will be placed on performance, weight and reusability. The design will be carried to the point at which engineering drawings of the devices, showing fabrication details, can be accomplished as part of this task. A development plan detailing the effort required to continue this task through to fabrication of a flight qualified device will be provided. Using this design, a prototype device will be built and tested under other parallel Space Tug tasks.

Approach: The approach for this task is outline in the following paragraphs:

1. Collect spacecraft and mission criteria applicable to the design of the surface tension device for the ACPS. This effort will be primarily aimed at defining the expected acceleration environment for the entire mission. Other system requirements such as propellant off-loading, emergency dump, etc., will also be established.

2. Various candidate surface tension devices, which appear to be capable of satisfying the mission requirements, will be identified. For this application, continuous communication or liner type devices are the only type of device which are capable of supplying propellant to the ACPS thrusters. Therefore, only various configurations of liner type devices will be considered as candidates. A preliminary evaluation of their capabilities will be accomplished. From this evaluation, the most promising concept will be selected.

3. A detailed analysis of the selected system will be accomplished. Its performance and capabilities will be optimized. The operation of the device throughout the mission will be evaluated to insure it has adequate design margins, sizing of the flow channels, configuring capillary barriers (if required) and the selection of screen materials will be the primary areas to be analyzed.

4. Factors such as reusability, reliability, loading, handling and compatibility will be evaluated to insure that the device will satisfy the multiple reuse requirements.

5. The structural design and fabrication of the device would be evaluated. The objective will be to provide sufficient structural strength, while minimizing weight. Results from the related fabrication technology task will be implemented. An engineering drawing, showing the fabrication details, will be made.

6. A development plan, presenting the effort necessary to continue the development of the device through to flight qualified hardware, will be written. Any necessary development testing will be identified.

Schedule: 4 months of effort with a final report.

Budget: 4 manmonths, 1 hour computer time

Facilities: None required.

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/s/ R. W. VandeKoppel
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Manager
Propulsion ER&D

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APPENDIX A

4.2 AVIONICS

(A-1 thru A-18)

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Docking SRT No. A-1

Task Title: Remote Manned and Autonomous Docking

Statement of Problem: The two modes of operation for the Tug docking maneuver are: Remote Manned and Autonomous. Neither of these modes of operation have been utilized, and thereby proven, in the U.S. space program. Thus, a considerable amount of effort will be required to establish a sufficient technology base from which the docking operational and hardware requirements can be defined. Docking simulations similar to those performed during the definition phase of the Apollo program will have to be performed.

The Remote Manned System required for the docking maneuver will involve a pilot controlling the Tug from a ground based control station. A TV camera on the Tug will provide the visual information needed by the pilot to perform the docking maneuver. The TV picture will be transmitted to the control station via a relay satellite (to be considered for some missions), a ground tracking network and a data processing center. Communication and processing time delays up to eight seconds are being predicted. Visual guidance errors for the final alignment of the Tug to the docking axis of the target will be obtained from a visual aid mounted on the target. Visual aids to be considered would be the Apollo standoff "tee" and the Apollo Soyuz standoff "box".

The autonomous docking system will involve a sensor aboard the Tug and a cooperative interface on the target. The capability of the control loop (the sensor, control logic and propulsion) to perform the docking within docking tolerances is in question.

Objective: The objective of this task is to provide a technology base which provides: 1) data on the interdependence of the Tug performance and subsystem requirements, 2) performance requirements for the most probable Remote Manned and Autonomous docking systems, and 3) docking operational approaches.

Part one of the objective provides data on the interdependence of the Tug requirements involved during the docking maneuver. Some of the requirements for the Remote Manned System are: control modes, acceleration levels, velocity levels, limit cycle bounds, types and tolerance bands of visual aids, TV type (mono/stereo), TV resolution and frame rate and navigation methods. As each of these requirements varied, the effect on the other requirements and such things a fuel consumption and performance time and accuracy must be determined. This data on the interdependence of requirements is critical to making effective Tug Project decisions on the impact of varying any of the requirements studied.

Part two of the objective will provide the performance requirements for a baseline docking system (remote manned and autonomous).

Part three of the objective will provide alternative docking approaches along with the advantages and disadvantages of each.

Approach: A series of moving base simulations will be required to study the remote and autonomous control of the docking maneuver properly. An empirical approach is the only method that can be used because the pilot and some of the guidance hardware must be physically introduced into the study. Simulation runs would be made for various combinations of the system variables (control modes, visual aid, time delay, TV resolution, etc.) to determine the effect on system performance. The objective of the study would be realized through this simulation approach.

Schedule: 16 months after Authority to Proceed (ATP).

Budget: Manpower - $920K = 350 manmonths
Computer - 80K = 2,000 HYBRID Console hrs. @ $40.00 per hr.)
Material - 10K
Hardware - 60K

Facilities: Six degree of freedom servo driven moving base simulator and computer.

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Approved: /s/ G. W. Smith
G. W. Smith, Manager
Manned Exp. & Life Sciences

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Systems Performance SRT No. A-2

Task Title: Docking Strategies Assessment

Statement of Problem: Docking with a cooperative passive satellite using an unmanned spacecraft requires the conversion of a variety of sensor data into appropriate vehicle responses. The sensitivities to errors in these responses will be extreme. Sophisticated logic will be required to interpret radar, optical and contact sensor data in terms of the complicated and highly dynamic nature of the two-vehicle relative geometry. The definition of the functional requirements of this on-board logic will require extensive simulation and analysis. The technologies required include rigid body dynamics (6 DOF), classical and dynamic filtering, modeling of hardware functions, pattern recognition, discrimination and/or enhancement, and optimal control theory. Experience in the application of these disciplines to the unmanned docking proglem is so limited that the driving technology issues may not yet be identified.

Objectives: The objective of this task is to define functional requirements for unmanned docking systems as a function of the level of autonomy required in the maneuver. The data needed to make this definition will result from hybrid simulations of the docking maneuver using alternative strategies and on-board software.

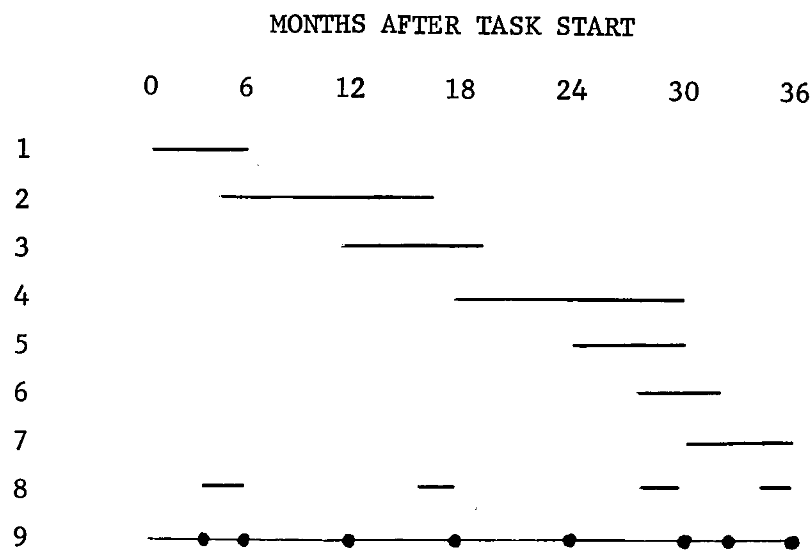
Approach: Preliminary analyses will be performed to produce a set of candidate navigation, data interpretation, and control policies. These policies will be implemented and used to perform closed-loop docking simulations. Based on simulation results, a second generation of policies will be developed. Comparative data will then be generated using a range of identical simulation conditions for all policies. The impact dynamics problem will be studied in detail by assessing the probability of docking success using the various policies. The continuing technology development requirements will then be assessed and a recommendation of the most promising types of on-board logic will be made.

Schedule and Budget: 200 manmonths beginning in 1975. 150 hours of computer time.

Events:

1. Develop candidate navigation, sensor data interpretation and control policies.

2. Incorporate policies into preliminary closed-loop simulations.
3. Generate second-generation control policies.
4. Evaluate policies through detailed comparative simulations
5. Assess probability of docking success.
6. Define requirements for recommended on-board docking software.
7. Identify further development requirements.
8. Document candidate policies and results.
9. Management Review.



<u>Facilities</u>: Task will be coupled with simulation tasks and associated equipment.

/s/ <u>R. D. Vaage</u>
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Approved: /s/ <u>R. J. Farrell</u>
R. J. Farrell
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Systems Performance SRT No. A-3

Task Title: Propellant Slosh Effects in Log-G Engironments

Statement of Problem: A liquid mass moving within a tank has a significant effect on vehicle motion. During Tug deployment and retrieval by the Shuttle, these effects must be considered for successful design of the docking mechanism. Slosh effects will be even more critical to successful docking of the Tug with the retrievable payload.

Objective: To determine slosh effects during Tug deployment/retrieval, payload docking, and main engine or ACS burns.

Approach: Formulate the equations of motion of the propellant including the effects of surface tension, contact angle, and slosh baffles. Couple these equations to the tank structure representation, including effects of viscous damping and tank bulging. Develop a 6 degree-of-freedom computer program to solve these equations for interaction forces and moments for any fluid level in the tank, with the applied force at any orientation to the vehicle center of gravity. Devise test methods and/or utilize flight data to verify analytical results.

Schedule and Budget: 60 manmonths as indicated below beginning in 1974. 35 hours of computer time.

Events:

1. Review state-of-the-art techniques and methodology.
2. Select modeling approach.
3. Derivation of equations of motion.
4. Computer program development.
5. Program refinement/expansion.
6. Program documentation.
7. In-house management reviews.

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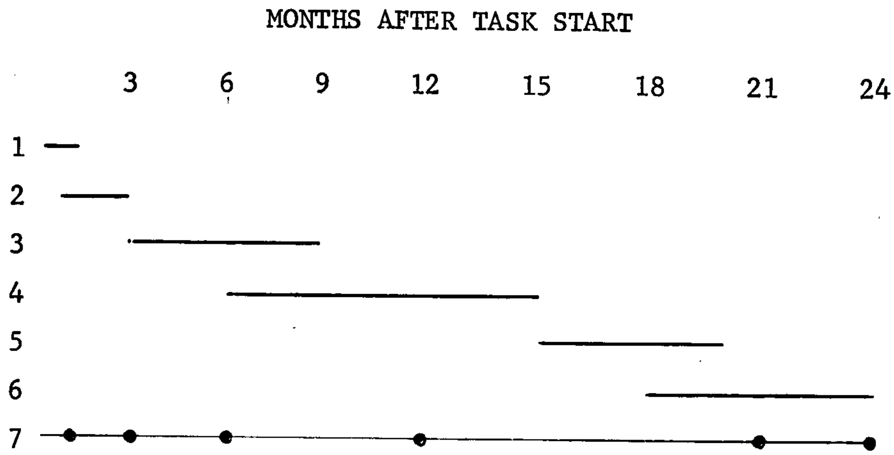

<u>Facilities:</u> Computer facilities assumed. No study peculiar hardware required.

/s/ <u>R. A. Zehnle</u>
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Approved: /s/ <u>R. J. Farrell</u>
R. J. Farrell
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Rendezvous and Docking System SRT No. A-4

Task Title: R. F. Target Signatures

Statement of Problem: Space Vehicle Targets are usually specified in terms of their average radar cross-section and scattering statistics. Since rendezvous and docking must be effected with a wide variety of target vehicles and target vehicle shapes, a concise understanding of target vehicle scattering characteristics must be obtained. The radar cross-section of target vehicles is a function of the target geometry, radar frequency and polarization, and radar antenna aspect angle. Target geometries for both military and non-military targets must be identified, and the radar cross-section for these targets must be obtained through theoretical calculations and experimental verification. Since very little data are currently available, theoretical and experimental data must be obtained at a number of r.f. frequencies and polarizations with emphasis in the X-band and K-band regions. These data are required to commence with a suitable rendezvous and docking radar design and to compare different system implementations. It is even more essential to arrive at minimum weight/ maximum reliability design for a Space Tug rendezvous system.

Objective: To tie down the scattering characteristics of various target vehicles which are expected to be employed in the Space Tug rendezvous and docking missions. Determine the radar cross-section variations with frequency, polarization, and aspect angle of various target vehicles including vehicles with complex geometries and shapes. Provide experimental verification of the radar cross-section of these vehicles by scale model measurements of the large target vehicles and full-scale measurements of the smaller vehicles. Assess the effectiveness of FD rendezvous radars for various targets, target geometries, and target scattering characteristics, and to determine the radar weight/power requirements for an effective Space Tug rendezvous radar.

Approach:

1. Identify target geometries for both military and non-military Spate Tug targets vehicles. Also establish smallest target for rendezvous task.

2. Determine theoretical variation of radar cross-section of simple shapes, and utilize computer programs to combine these

cross-section contributions to arrive at the overall scattering characteristics of various Space Tug target vehicles.

3. Arrive at 4 to 5 viable target categories and classify targets according to size and complexity.

4. Build scale models of larger space vehicle targets and obtain full-scale test models of smaller targets for radar cross-section measurements.

5. Perform radar cross-section measurements; indoor measurements on scale models in radar anechoic chamber and full-scale model measurements at RATSCAT facility. Holloman AFB, Almagordo, N.M. Radar cross-section measurements will be performed for parallel and perpendicular polarization at h-band, x-band, and k-band.

7. Determine range of aspect angles for space rendezvous and analyze radar cross-section data for basic radar design purposes.

8. Determine rendezvous radar design and effectiveness of FD radar for all targets considered in Space Tug mission.

9. Write report on radar cross-section calculations and measurements.

10. Write report on basic radar design and effectiveness.

Schedule: (See Approach) - Completion dates:

Item 1 - 6 weeks after go-ahead
Item 2 - 3 months after go-ahead
Item 3 - 4 months after go-ahead
Item 4 - 6 months after go-ahead
Item 5 - 9 months after go-ahead
Item 6 - 9 months after go-ahead
Item 7 - 10 months after go-ahead
Item 8 - 12 months after go-ahead
Item 9 - 14 months after go-ahead
Item 10 - 15 months after go-ahead

Budget: Approximately $150K to $250K

Facilities: Computer facilities for calculations; Model Shop for building scale models; Radar Cross-Section Facility for scale models (subcontract); Radar Cross-Section Facility for full-scale measurements (RATSCAT).

/s/ Werner Koppl
Werner Kopple
Dept. 1610, Ext. 2092

/s/ R. L. Gates
R. L. Gates
Guidance and Control Technology
Panel Chairman

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Scanning Laser Radar (SLR) for Rendwzvous and Docking
SRT No. A-5

Task Title: SLR Receiver Application as a Star Tracker

Statement of Problem: The Scanning Laser Radar (SLR) has been developed and development is continuing by ITT Gilfillan, San Frenando, California, under contracts with NASA/MSFC, Huntsville, Alabama. Its specific purpose is for rendezvous, stationkeeping, and docking in the Space Shuttle Program, and it is applicable also to the Space Tug. The SLR is designed to operate with a pulsing Gallium-Arsenide (GaAs) Laser of a wavelength of approximately 0.9 micron (just beyond the visual range). Other laser radars, using YAG lasers at 1.06 micron wavelength and CO_2 lasers at 10.6 microns wavelength, are also under development by ITT Gilfillan, Norden Division of United Aircraft Corporation, and GTE Sylvania.

The receiving component of the SLR is essentially a star tracker, except that it is currently designed to operate with a pulsing laser at the laser's wavelength, rather than with stars. Modifying and SLR receiver's circuitry and photodetector to operate both with stars and with the pulsed GaAs laser will allow its dual use as a star tracker and as the SLR receiver. This task is to determine the feasibility of this modification and its use for Space Tug.

Objective: The objectives are to demonstrate a combination star tracker and SLR receiver and to determine whether system requirements will allow a single instrument to function both as a star tracker for celestial navigation and as an SLR receiver for rendezvous, stationkeeping, and docking operations.

Approach: The approach will be to study: 1) the possibility for time-sharing this instrument as a star tracker for updating of the Inertial Measurement Unit (IMU) and other uses for a star tracker, with functions as an SLR receiver for rendezvous, stationkeeping, and docking operations; 2) the mechanical gimbaling or other mounting requirements to allow the single instrument to perform the two separate functions; 3) the system impact of the above three factors as to power, weight, volume, operational aspects, complexity, and reliability; and 4) to demonstrate an instrument with capabilities for these, and possibly additional functions. ITT Gilfillan has built the existing SLR and has also built a Multi-Mode Optical

Sensor (MMOS). In combination, the two would have the desired capabilities.

Schedule: One year program, commencing in July 1974.

Budget:

Study: One man year
Hardware Demonstration: Two man years and $50K material, plus the SLR and the MMOS as GFE.

Facilities: Existing electro-optical laboratory with capabilities for star and target simulation and measurements.

/s/ William R. Wilson
William R. Wilson
Dept. 1625, Ext. 3927

Approved: /s/ R. L. Gates
R. L. Gates, Chairman
Guidance and Control
Technology Panel

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Systems Performance SRT No. A-6

Task Title: Terminal-Phase Rendezvous Navigation and Guidance

Statement of Problem: As the active vehicle in a rendezvous maneuver enters the region where two-vehicle relative motion is important, simultaneous determination of the active vehicles state in inertial space and its state relative to the target must be accomplished. Absolute and relative navigation sensors will be operating. The logic for acquiring the target vehicle will also be exercised. Steering strategies that take into account the orbital mechanics of both vehicles will be utilized to take the active vehicle to the vicinity of the passive vehicle. The degree of sophistication required in the sensors and on-board logic for: a) acquisition, b) simultaneous absolute and relative navigation, and c) rendezvous steering has not been adequately assessed to determine the software functional requirements.

Objective: The objective is to develop data that will permit a definition of the level of sophistication required by the on-board navigation and guidance systems to perform the rendezvous segments of the Space Tug missions and to determine measurement strategies for those segments. In addition, the objective is to develop the data needed to define the functional requirements for target acquisition logic and to define the mechanisms for a transition to and from absolute and relative navigation and guidance.

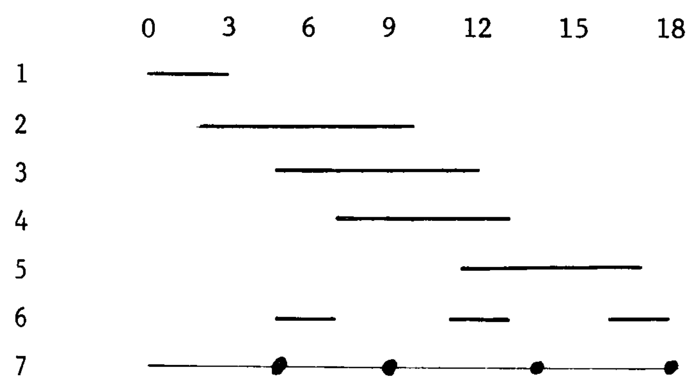
Approach: Linear error analysis programs will be extended to incorporate trajectory segments in which both absolute and relative measurements are being processed. Utilizing these programs, measurement strategies will be developed which include pre-terminal phase navigation update requirements and measurement frequency and quality requirements for all sensors during the transfer phase. Candidate steering laws will be programmed in a range of sophistication from line-of-sight to second-order closed-form solutions. Detailed closed-loop simulations will be performed using the guidance laws to establish guidance performance requirements for the on-board logic. Target acquisition strategies will be evaluated by simulation and the probabilities of acquisition success will be established as a function of sensor and geometric parameters.

Schedule and Budget: 60 manmonths beginning in 1974. 35 hours of computer time.

Events:

1. Extend current programs to include absolute and relative measurements.
2. Expand library of candidate steering laws.
3. Assess measurement requirements for candidate sensors.
4. Define guidance performance requirements for on-board logic based on closed-loop simulations.
5. Develop acquisition strategies and assess probability of success.
6. Document programs and requirements.
7. Management Review.

MONTHS AFTER TASK START



Facilities: Computer availability assumed. No study peculiar equipment required.

/s/ R. D. Vaage
R. D. Vaage
Dept. 0442, Ext. 3121

Approved: /s/ R. J. Farrell
R. J. Farrell
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Systems Performance SRT No. A-7

Task Title: Guidance and Navigation Strategy Assessment for High-Volume Space Tug Operations

Statement of Problem: Navigation and closed-loop steering policies for preterminal phase of Space Tug operations must be established which not only provide adequate mission performance for a wide range of mission types but also are capable of flying with minimal preflight analysis. The determination of the appropriate techniques for on-board software requires detailed targeting, error analysis, and simulation studies. A variety of navigation and guidance systems must be modeled and flown in modeled environments. A large number of trade-offs exist due to the potential use of navigation information from the Shuttle, the payload navigation satellites, and/or a variety of both ground and orbiting measuring devices. The determination of strategies and profile for on-board G & N must be followed by the development of software to determine the flight-specific constants in a rapid manner. Targeting program malfunctions will be required in order to be compatible with the flight frequencies.

Objective: The objective is to produce sufficient error analysis and simulation data to permit the definition of Space Tug hardware and on-board software functional requirements. This includes the digital simulation and analysis of sufficient hardware, software, and procedural alternatives to produce the trade-off data needed for a definition of on-board, ground support and preflight guidance and navigation functional requirements.

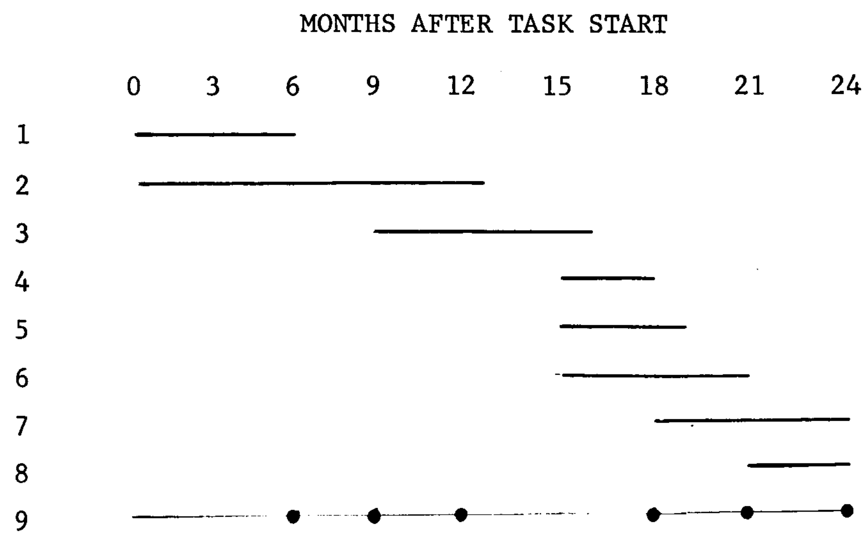
Approach: A three-dimensional matrix of missions, candidate G&N subsystems, and G&N procedures will be sugjected to detailed linear error analysis. Sensitivity of results to error source model parameters will be conducted. A selection of matrix elements will be made based on the linear error analysis data and detailed nonlinear simulations will be performed. Worst case situations will be identified during the simulation activities. Steering law alternatives will be studied via closed-loop simulation on the worst case trajectories in order to establish performance requirements for the on-board logic. Preflight targeting requirements will be determined and programs will be modified to automate the determination of guidance constants for the most promising guidance strategy. The linear error analysis will include studies to 1) determine the accuracy potential of the G&N

system for all identified mission modes, 2) determine data rates (update frequencies) for the various sensors, and 3) determine by coincident simulations, whether the estimated vehicle states obtained by linear covariance analysis do indeed converge to actual values within reasonable bounds specified by the covariance matrices. Re-examination of the basic assumptions and the suitability of the measurements for their respective applications will be made for cases where the statistical estimates fail to converge to actual values computed in a "real world" simulation.

Schedule and Budget: 110 manmonths beginning in 1974. 70 hours of computer time.

Events:

1. Define candidate missions, G&N subsystems and procedures.
2. Perform detailed linear error analyses.
3. Perform nonlinear navigation simulations for selected cases.
4. Re-examine navigation policies for nonconvergent simulations.
5. Perform closed-loop combined G&N simulations of worst case trajectories.
6. Modify existing programs to automate guidance parameter selection.
7. Checkout and Document program modifications.
8. Identify further development requirements.
9. Management Reviews.



Facilities: Computer availability assumed. No study peculiar equipment required.

/s/ J.K. Willoughby/R.D. Vaage
Dept. 0442, Ext. 3121

Approved: /s/ R. J. Farrell
R. J. Farrell
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Star Tracker SRT No. A-8

Task Title: Target Vehicle Signatures as Star Tracker Targets

Statement of Problem: Under many conditions a target vehicle will resemble a star, as seen from another location. This may result from reflection of ambient sunlight, a beacon on the vehicle, or from illumination of the vehicle or retro-reflectors on the vehicle by a light source at the "other" location. The problem is, "can a star tracker be used to acquire and track a target vehicle?"

Objective: The objective is to determine the feasibility of using a star tracker to acquire and track a target vehicle.

Approach: 1) Study acquisition and tracking capabilities of current start trackers, 2) Study the light reflected or radiated by all types of target vehicles, both active and passive, giving consideration to all possible sources of light. The apparent angular size of the reflected or radiated light, as seen by the star tracker, shall be included. Utilize and continue studies and tests (some of which have been classified to catalog "signatures" of radiation reflected or emanating from all targets of interest to the Space Tug Program, 3) Study the gimbaling and other mounting requirements to allow the star tracker's use with target vehicles, and 4) Consider system requirements implied in this use of star trackers.

Schedule: Studies: One year Program. Signature Tests: Possible large program, depending on availability of information from previous (classified) work.

Budget: Studies: Two man years. Signature Tests: See comment under "schedule".

Facilities: Existing electro-optical laboratories, with capabilities for star and target simulations, and capability for illuminating test targets with lasers, solar simulators and other light sources.

/s/ William R. Wilson
William R. Wilson
Dept. 1625, Ext. 3927

Approved: /s/ R. L. Gates
R. L. Gates, Chairman
Guidance and Control
Technology Panel

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: SRT No. A-9

Task Title: Autonomous Navigation Technology for Space Tug

Statement of Problem: A number of sensor types especially suited for autonomous navigation applications have been developed, or are under development at the present time. These sensors and their associated ancillary support systems have been considered mostly in connection with the low altitude (100 - 200 NM) type of mission and with the on-orbit phase of these missions. Little attention has been paid to the problem of autonomous navigation at intermediate and high altitudes (geosynchronous), or during the highly eccentric transition phases between the parking orbit and the mission orbit. The problems that arise are due to the practical considerations of detection and acquisition, the operational considerations of global and tempus converge, and the analytical considerations of software adequacy and implementation. The special conditions and exigencies that affect an autonomous G&N system at synchronous altitude and during the transfer orbit phases require an in-depth study of the utility and the possible limitations of proposed autonomous navigation sensors, particularly: The Interferometer Landmark Tracker (ILT), a One-Way Doppler (OWD), a Star Mapper (SM), and a Horizon Sensor (HS) in addition to the conventional IMU system.

Approach: Simulations will be conducted employing a trajectory error analysis program equipped with at least the aforementioned autonomous navigation sensors, IMU and ground tracker models. These simulations will analyze a typical Space Tug mission with times lines and actual landmark distributions and transmitter power (classified data) in order to determine: 1) the feasibility of detection and acquisition, 2) the accuracy of the on-board navigator (by error analysis under simulated operational conditions), 3) the relative contribution of the navigation sensors used independently or in combination, 4) the adequacy of the G&N system during various phases of the Tug mission. Based on these simulations and manufacturer specifications for each instrument, certain affected Tug subsystems will be sized for that particular useage and pacing items that may have a critical impact upon Tug performance and scope of mission will be identified. The feasibility of upgrading sensor performance for certain sensor types will be investigated. One possible improvement would be an integration of ILT and OWD into a single device, exploiting a common antenna, receiver, search and retrieval logic memory. Other, more exotic sensor types will be examined in concept and by error analysis processes where appropriate.

Objective: The objective of this task is to determine the contribution of the autonomous navigation sensors ILT, OWD, SM and HS to intermediate and high altitude missions and to delineate possible constraints pertaining to the use of these sensors in that environment. Secondarily, the affect that the G&N subsystem has upon sizing other key space Tug subsystems directly with respect to power, weight, stabilization, etc., or indirectly with respect to tankage, propulsion, computer, etc., will ve investigated.

Schedule: 12 month program

Budget: 24 manmonths. $10K computer usage

Facilities: None

/s/ Howard Garcia
Dept. 0450, Ext.

Approved: /s/ R. L. Gates
R. L. Gates, Chairman
Guidance and Control
Technology Panel

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Avionics SRT No. A-10

Task Title: Inertial Measurement Units Evaluation and Selection

Statement of Problem: An Inertial Measurement Unit (IMU) must be selected for the Tug mission with emphasis on reliability and weight. This will be followed by a laboratory evaluation of the selected system/s.

Objective: The objective of this task is to select several candidate IMUs for the Tug mission and to evaluate them in the laboratory to the required environmental constraints.

Approach: 1) Perform selection based on Tug constraints, 2) Procure three systems, 3) Run independent evaluations of candidate hardware against mission modes and environment and check compatability with Flexible Signal Interface. Check out redundancy concept to verify soft performance failures. Implement star sensor and/or horizon sensor update to platform.

Schedule: 13 month program.

Budget: Hardware - $500K
Evaluation Phase - 3 engineers, 2 techs. (2 years)

Facilities: 3 axis table
Single axis rate table
Electro-optical Alignment setup
(and supporting test equipment)

/s/ Roger T. Schappel
Dept. No. 1625, Ext. 3982/5053

Approved: /s/ R. L. Gates
R. L. Gates, Chairman
Guidance and Control
Technology Panel

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Communications SRT No. A-11

Task Title: Planar Array Antenna

Statement of Problem: A high gain (20 to 25 db) S-Band antenna system is required for two-way tracking and communications between the Tug and, a) existing ground stations, b) relay satellites, and c) the shuttle vehicle. Full coverage of all possible look angles is required. A bandwidth of around 20% is required to provide two-way links to all ground stations and vehicles.

Current system design uses two antennas, each covering a hemisphere. Gimballed dishes have been ruled out because their shape does not permit easy packing during launch. Electronically steerable phased arrays are ruled out because of complexity and limited steering range. The preferred antenna is, therefore, a planar phased array without electronic steering, gimballed to cover the hemispherical scan requirement. The electrical problem is to design a compact, lightweight, low loss feed system for an array of approximately 100 elements, and integrate lightweight elements with this feed system to form an integrated antenna.

Objective: The objective is to design and build a prototype of this antenna in order to demonstrate feasibility and determine the expected weight and performance of a flight article.

Approach: A stripline feed circuit and printed circuit dipole elements will be designed. The assembled antenna will be tested for electrical performance and subjected to environmental tests.

Schedule: 12 months

Budget: 24 manmonths (Engineering & Technicians) $30K
Materials 3K

Facilities: No new facility needed. Antenna lab, printed circuit shop, and environmental laboratories will be used.

/s/ R. J. Richardson
R. J. Richardson
Dept. 1620, Ext. 3246

Approved: /s/ R. H. Hardin
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Communications SRT No. A-12

Task Title: One Way Doppler and Emergency Command Receiver

Statement of Problem: Tug DOD Missions conducted under Autonomy Level #2 do not allow the ground to provide navigation updates over the command link. It presently appears most cost effective to provide this update by onboard computation of one way doppler shift of known ground transmitters (serving other functions) operating in the 1750 to 1850 MHz frequency range.

There are scanning frequency receivers used for DOD oriented classified missions. However, these are, in general, far overdesigned, heavy, expensive, and still not too applicable to Tug requirements.

Approach:

1. Design and demonstrate circuits for a one and one-third pound RF receiver capable of scanning the range 1750 to 1850 MHz.
2. Assume that the precision stable oscillator input requirement for frequency synthesize will be provided by the Tug Data Management Subsystem (Stability Requirements - TBD).
3. Include with the receiver the capability of demodulating the SGLS compatible 2,000 bit per second command subcarrier.
4. Provide bit stream, command close adequate signal level uninhibit (or squelch) command, an indication of input frequency (synthesizer settings), and an input signal strength indication to a connector for connection to the Tug Data Management Subsystem.
5. Plan an incorporation of a standard set of 4 hybrid circuits (one ounce), providing all other command and telemetry interface functions to/from Tug Data Management Subsystem through a second 4-pin connector. Example, commands to go from doppler search to command receive mode and inverse.
6. Assume the Tug Data Management Subsystem will extract all needed one way doppler shift data for navigation updates by internal computation using a program containing information on known RF ground sources and its own (Tug) approximate position.

Schedule: Start April 1974, complete July 1975 with complete interface specifications generated by end of May 1975. (15 month time span).

Budget:	48 manmonths (Engineering & Technicians)	$125K
	Materials	50K

Facilities: No new facility needed. MMC-RDL RF laboratories and equipment are assumed.

/s/ N. R. Sheppard

N. R. Sheppard
Dept. 0453, Ext. 2405

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Data Management SRT No. A-13

Task Title: Flexible Signal Interface

Statement of Problem: In the present funding environment, there is a growing need to control overall program costs. The Data Management Subsystem (DMS) has a considerable effect on overall cost since its design can determine the effect that a change or modification to one subsystem has on other interacting subsystems. The characteristics of the DMS that are most influential in this area are: flexibility, ease of change, case of refurbishment, ease of launch preparation, graceful growth, reliability and cost. Graceful growth is defined as being able to provide a basic interface that will allow orderly and economic improvements in avionics boxes to be incorporated into the vehicle. DMS progressed from the original centralized subsystem that was an outgrowth of the telemetry subsystem to the present decentralized system which was developed primarily as a means of saving weight through removal of many long wires. The biggest difficulty with this latter method is that the other subsystems utilizing the data management subsystem each have a multitude of different interface requirements. This means that the DMS is required to process both ac and dc analog signals of various maximum amplitudes, similar bi-level signals and binary signals of various magnitudes and waveforms. A standardized method of handling these needs to be developed.

Objective: The objective of this task is to develop and test a minimum DMS prototype that will provide the flexibility needed to process all of the user subsystem signals efficiently and that has the capability of being easily changed and modified to meet the varying requirement of different missions and of new and modernized interfacing subsystems. The minimum DMS will consist of redundant central control units and three or more bus interface units. These interface units will include dedicated branch circuits that are to be incorporated into large user subsystems and non-dedicated branch boxes for small user subsystems. State-of-the-art circuitry such as LSI and hybrid circuits should be used for the central control units and the interface units.

Approach: The task approach will be to utilize time division multiplexing (TDM) on the data bus. All data will be digitized for bit serial transmission at a 2 MHz rate on the bus. The interconnecting wires will consist of two redundant shielded twisted pair for control and two redundant shielded twisted pair for data. The two data buses will each accommodate full duplex transmission of data, i.e., to and from each interface unit.

The central control units will consist of two general purpose digital processors (for the minimum system), a common modular memory and two command, data, timing and checkout (CDTC) processors. One of the general purpose processors is used for control and the other for monitor. The controlling general purpose (GP) processor performs the guidance and navigation computations using inputs from the Inertial Measurement Unit (IMU) and the DMS. Data transfers are controlled by the GP processor through the CDTC by utilizing a dedicated portion of the common memory. The GP processor performs this control by selecting which part of the memory is used by the CDTCs for generation of the data transfer command words. These data transfer command words are used by the interface units to send or receive data from the interfacing subsystems, to respond to commands from the GP processor, to perform self-checks and to transmit the results of these self checks as status data. The status data and other pertinent data can also be utilized by the GP processor to perform limit checks and trend analyses.

The dedicated branch circuits that are incorporated in the large user subsystems contain all of the basic circuitry for the standard flexible interface unit. This includes the control and data input line receivers and the data output line drivers, the command and control decoders, timing and sync detection and generation circuits, data multiplexers and demultiplexers, signal conditioners (level translators, ac/dc and dc/ac converters, A/D and D/A converters) and the necessary control logic, buffering and storage.

The GP processors will be state-of-the-art microprocessors that include a central processor unit, buffers and multiplexers, control logic and sufficient memory and word length for it to perform its various functions. The two GP processors will operate in a pilot/co-pilot mode with the co-pilot monitoring the performance of the pilot. In the event of a disagreement, both GP processors will perform a self-check. If no decision can be made from the self-check results, provision will be made for turning on a third GP processor (not to be provided) to enable a majority vote. Consideration should also be given to including some self-repair capability into the GP processors in conjunction with the self-test capability.

The common modular memory portion of the central control units shall be of sufficient size so that the GP processors can perform their functions without having to use most of the memory's storage capability. That is, sufficient memory should be provided so that the GP processor's programs do not have to resort to clevel schemes and tricks to save memory. This is necessary because the cost of programming goes up exponentially as the capacity of the memory is approached. Thus a larger memory may cost somewhat more in dollars, weight, size and power, but this is more than compensated for by the resultant dollar savings in programming. The memory must also have sufficient expansion capability so that this capability can be maintained throughout the life of the DMS. This capability is particularly important in the DMS program because of the expected changes due to missions and interfacing subsystems changes and modernizations.

The CDTC processors obtain the DMS control commands from that portion of the common memory selected by the GP processor according to the operating mode of the vehicle. Its primary function is to provide command words and timing signals to the dedicated branch circuits and the branch boxes so that data is transferred from subsystem to subsystem in an orderly manner. In addition, it performs a monitoring function using the status data words from the data bus and alerts the GP processor to any abnormalities that occur in any of the user subsystems. The operation of the two CDTC processors is monitored by the GP processors for appropriate action in the event of malfunctions in the CDTC processors.

In general, the approach will be to strive for maximum flexibility with due regard for cost, weight, size and power consumption. Maximum use of state-of-the-art components will be made with due consideration again for cost and for reasonable obtainability and reliability.

The DMS subsystem test will be sufficient to show that the subsystem performs the required functions.

Schedule:

Design Phase (includes breadboard of critical circuits	6 months
Fabrication Phase	10 months
Documentation Phase (Final Report)	2 months
TOTAL Program Span	18 months

Budget:

Manpower	$380K, 150 manmonths
Material	100K
Travel	20K
TOTAL	$500K

Facilities: Hybrid circuit fabrication equipment, standard electronics and data management test equipment.

/s/ R. O. Leighou
Dept. 1620, Ext. 4624

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Tug Electrical Power Subsystem SRT No. A-14

Task Title: Design of Roll-Up Solar Array System

Statement of Problem: Roll-up solar array system has been designed and tested by GE and Hughes. They were developed on an applied research basis and were not designed for a specific space vehicle. Advanced development is thus required based on Tug-peculiar operational and vehicle design requirements. The critical requirements and associated problem areas are as follows:

1. Deploy/Retract Cycle - Approximately 600 cycles are required. The developed system has demonstrated only a fraction of this number (less than 50). Deployment boom and actuating mechanism must be evaluated for compatibility and total deploy/retract capability demonstrated.

2. Solar Cell Assembly - Solar cell cover type and thickness, cell interconnection technique, number of series and parallel combination, etc., are Tug-peculiar requirements. Each of these areas must be selected or designed and incorporated into the Tug Solar Array System.

3. Refurbishment and Maintenance - Hardware reuse is a brand new consideration peculiar to all Shuttle applications. All aspects of the solar array design such as array blanket, solar cell module, dc motors, and deploy booms should consider replacement, repair, and checkout requirements with the basic objective of minimizing operational cost.

4. Thermal Environment - The developed system was not specifically designed for operation in both lower earth orbits and synchronous orbits. The solar array temperature can be as low as $-190^{\circ}C$. The solar cell interconnection technique and materials must be compatible with the cold Tug environment.

5. Structural Design - The deployed solar array must be capable of withstanding at least 0.1 g load from RCS thruster firing. In addition, a trade-off between weight, number of deploy/retract cycle, array aspect ratio (length to width), and battery depth of discharge may result in a requirement to design the deployment boom to withstand up to 3.5 g's from main engine firing. (At present, this is not required.)

Objective:

1. Design and develop a prototype roll-out solar array system for Tug utilizing the basic technology developed under the JPL/NASA Contract NAS7-100.

2. Demonstrate full deploy/retract operation of at least 600 cycles.

Approach: Either of the following approaches are recommended:

1. Issue a joint contract between the prime contractor and the solar array manufacturer (GE or Hughes, awarded on a competitive basis) to develop an advance prototype Tug roll-out solar array design. The contractor will coordinate all design activities in conjunction with their Tug design.

2. NASA/DOD will handle all direct design activities with the selected solar array manufacturer. The Tug contractor will provide technical support to NASA/DOD.

For either approach, only 10% of the array surface will be covered with actual solar cells to minimize the overall program cost.

Schedule: 16 month time span.

Budget: Manpower: 60 manmonths
Material, Hardware, Misc. - $100K

/s/ M. S. Imamura

M. S. Imamura
Dept. 0455, Ext. 4065

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Electrical Power SRT No. A-15

Task Title: "Blue" Solar Cell Evaluation

Statement of Problem: New Solar cell with higher response than that of conventional cell in the visible light spectrum has been developed by COMSAT Corporation. The cells incorporated basic changes in the metal grid design and in the thickness of diffused N-layer. Because of increased power conversion efficiency (14 to 16% vs 10 to 12% for conventional cells), they are attractive in reducing the required solar array area and thus the weight of the solar array. However, its mechanical integrity under thermal environment of a roll-out solar array in the synchronous orbit are unknown and must be carefully evaluated.

Electrical characteristics under various light intensities and temperature conditions are not available. These characteristics are mandatory in determining the size and weight of solar arrays not only for Tug/Transtage applications, but also for any other vehicle utilizing these cells.

Objectives:

1. Evaluate metal contact and diffused layer integrity under Tug thermal environments.

2. Determine electrical characteristics at various temperatures and light intensities and the temperature coefficients.

Approach: Purchase about 50 cells from Centralab and use MMC facilities for the required testing. Prepare an evaluation report.

Schedule: 6 month time span.

Budget: Manpower: 10 manmonths
Material: $2,500

/s/ M. S. Imamura

M. S. Imamura
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SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Electrical Power SRT No. A-16

Task Title: Battery Development and Evaluation

Statement of Problem: Silver-Zinc (Ag-Zn) battery has been baselined for use on Tug and Transtage/Shuttle missions by themselves and also in conjunction with the solar array. They have limited recharge capability, depending on type of electrode separator materials used. Insufficient data and knowledge of specific Ag-Zn design are available to be able to select the best one for immediate Tug, Transtage, and other Shuttle applications.

Because of assumed recharge limitations, Ag-Zn battery reuse for successive flights is restricted to two times. The predicted number of flights is as high as 350. If a selected design is empirically shown to be capable of multiple reuses, a significant cost reduction can be effected.

The Silver-Cadmium (Ag-Cd) battery has been used on spacecraft. It has a lower energy density but a higher cycle life capability than the Ag-Zn system. The basic problem is not with the battery itself but in how to control the recharge. The requirement for multiple reuses and hence reduction in cost are sufficient reasons to warrant a limited empirical evaluation of this system.

Metal-gas battery systems such as Silver-Hydrogen (Ag-H_2) and Nickel-Hydrogen (Ni-H_2) have recently shown high promise as long cycle life device approaching the conventional Nickel-Cadmium cell capability. Their energy density capability is close to the Ag-Zn. Their main advantage to the Ag-Zn is their higher cycle life capability. Some basic development work is in progress. Early data demonstrate that they can achieve technical maturity perhaps in two years.

Lithium battery, non-aqueous electrolyte type, has been developed. Their size, however, is limited to "D" size, small capacity types. This is a primary battery in a real sense that it cannot be recharged. The projected energy density is higher than the Ag-Zn by a factor of at least two to three and cost lower by about half. Development of a capacity rating as high as 100 to 200 AH appears feasible using the state-of-the-art technology. This battery system has not been used for space applications, and therefore must be fully evaluated.

Lithium-water battery with an unusually high energy density (at least 960 WH/LB) is presently being developed for both military and commercial applications. Development and evaluation for space applications are necessary before this system can be seriously considered for use on Tug. It is, nevertheless, very attractive as a super-low-weight primary battery system with possible multiple reuses with minimum refurbishment.

Objectives:

1. Evaluate and select candidate Ag-Zn cell designs and perform limited characterization tests (thermal, pressure, and electrical) on these cells. Determine cycle life capability at several depths of discharge and temperature.

2. Perform limited electrical and cycle testing on Ag-Cd battery cells and define charge control criteria. Evaluate its applicability to Tug/Transtage program.

3. Evaluate available metal-gas battery systems for applicability to Shuttle-related vehicles. Perform limited testing on selected battery system.

4. Develop 100 and 200 ampere-hour Lithium non-aqueous electrolyte battery cells and perform basic characterization tests.

5. Develop Lithium-water battery system and perform basic characterization tests.

Approach: The relative time of availability of various battery systems are projected as follows:

Ag-Zn	- 1973
Ag-Cd	- 1973
Metal-gas Lithium, non-aqueous electrolyte Lithium-water	1975 to 1977, with adequate government funding

The development of metal-gas and Lithium batteries have accelerated within the last two years. However, they have not attained a reasonable level of technical maturity. The Ag-Zn and Ag-Cd systems will be the primary candidates for all Shuttle-related vehicles well into the 1980's.

The basic approach, therefore, is to perform detailed evaluation work on the Ag-Zn and Ag-Cd battery for immediate Tug applications, and only limited evaluation of other battery systems. The following battery types will be developed for evaluation:

	Quantity
Metal-gas Ag-H_2 or Ni-H_2 cell	2
Lithium, non-aqueous electrolyte cells, 100 and 200 ampere-hour sizes	20 ea
Lithium-water cell, 1 KW	1

Schedule:

1. Ag-Zn and Ag-Cd battery — 14 mo. time span
2. Metal-gas battery — 14 mo. time span
3. Lithium non-aqueous electrolyte battery — 18 mo. time span
4. Lithium-water battery — 18 mo. time span

Budget:

	MM	Material	Development
1. Ag-Zn and Ag-Cd battery	20	$25,000	
2. Metal-gas battery			
Design and Fabrication			$ 20,000
Testing	16	$ 1,000	
3. Lithium, non-aqneous electrolyte battery			
Design and Fabrication			$ 80,000
Testing	20	$ 1,000	
4. Lithium-water battery			
Design and Fabrication			$100,000
Testing	20	$ 1,500	

/s/ M. S. Imamura

M. S. Imamura
Dept. 0455, Ext. 4065

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Electrical Power SRT No. A-17

Task Title: Multiplexed Power Distribution Control and Monitoring System Development

Statement of Problem: Unique wires dedicated for each monitoring and control function, as is the present practice, results in a large number of signal wires and associated connectors on components. These wiring and connectors present a significant portion of the total vehicle weight; and they are very costly. To meet the low cost, low weight requirements of the Storable Tug and other future spacecraft, control and data transfer harness is one of the few areas in which significant cost and weight reduction can be made.

Overall compatibility between the software and hardware must be evaluated. Although the basic components utilized in the multiplexed system are not new, the application of central data management system using the "data bus" concept to the spacecraft is essentially at an infant stage.

The incorporation of digital interface circuits in the user equipment is a new concept. All analog-digital conversion is provided in the "Branch" circuits. Thus, total signal interface compatibility between the user equipment and the central data management system must be demonstrated.

Objectives:

1. Design a complete system capable of monitoring and controlling power system components and load control devices using data bus concept.

2. Develop monitoring and control data bus interface units for power system components.

3. Develop a multiplexed system capable of providing interface data sampling, timing, and command distribution.

4. Build a partial Tug power distribution system and demonstrate control and monitoring capability.

5. Develop interface time mux to wire mux branching interface circuits.

6. Demonstrate software/hardware compatibility.

Approach:

1. Carry out a "paper design" for a complex system with special mphasis on the inter-Black-Box and inter-vehicle distribution techniques for power, control, and data interchange.

2. Design interface circuits which can be supplied for incorporation in a "User" Black-Box capable of:

   a) Switching power input on and off in response to central (computer-type) control.

   b) Providing Time Division Multiplex to Wire Division Multiplex (and inverse) conversion for control input and Data Monitoring output interface from/to common distribution buses.

   This task involves selection of switching, sensing, and logic devices together with circuit design, breadboarding, testing and some hybrid packaging design.

3. Study proper mix of "User" internal power control, fault isolation, regulation, and load limiting as traded against central control using high capability "branching" capability (Item 2 above). Design implementing circuitry and/or software approach complementing Item 2.

4. Show by at least two implemented "Hybrid Circuits" how logic for User Dedicated Circuitry can be implemented with no more than (5) hybrid devices plus switch and current limiting device.

5. Build interface circuitry and a software program for a GP Minicomputer suitable to demonstrate dedicated interface circuitry and power management techniques.

6. Evaluate various factors such as flexibility of software changes and implementation, data and control input/output formats, and data bus/computer compatibility.

Schedule: 12 months time span

Budget: 50 manmonths, $20K Material

/s/ M. S. Imamura
M. S. Imamura
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SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Electrical Systems SRT No. A-18

Task Title: Electrical Umbilical Connection System

Statement of Problem: Most Shuttle Payloads require electrical interfaces which must be capable of being automatically connected and separated a number of times while in orbit. In addition, capability to provide appropriate mated/unmated electrical signals must be provided. These types of umbilical devices have not been previously designed and are unique to the Shuttle Payloads.

Objective: Design and build a prototype connecting system capable of providing electrical connection and quick disconnect capability in orbit, and demonstrate its performance.

Approach:

1. Evaluate various concepts and umbilical devices available.

2. Investigate various design problems such as alignment, proper mating, translation and rotational requirements, and allowable tolerances between Tug and cradle mounting.

3. Evaluate various standardizing concepts considering safety, reliability, performance, cost, and weight.

Schedule: 14 month time span.

Budget: 20 manmonths, $15K material

/s/ M. S. Imamura
M. S. Imamura
Dept. 0455, Ext. 4065

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APPENDIX A

4.3 STRUCTURES

(S-1 thru S-16)

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Structures and Materials SRT No. S-1

Task Title: Composite Material Characterization

Statement of Problem: With graphite/epoxy composites being considered for use as a skirt material between fuel and oxidizer tanks as well as a primary pressure vessel material, it is important to have full knowledge of the physical and thermochemical properties of these materials after exposure to the Tug mission natural and artificially induced environments.

Objective: The objective in this task is to select the best candidate composite system for Tug pressure vessel and skirt applications after experimental evaluation of several candidate systems.

Approach: Existing graphite/epoxy systems will be evaluated to determine most suitable candidates for Tug application. The two or three most promising systems will be completely characterized by physical properties measurements and thermal analyses techniques before and after exposure to anticipated Tug thermal/vacuum/radiation environments. From this study will come the system or systems showing greatest potential as verified by actual physical property measurements. Long life data (several months to several years) will be predicted using a combination of Arrhenius rate equations and time-temperature superposition techniques.

Schedule: (Milestones)

Task	Months after Go-Ahead
ATP 2-1-74	
Candidate Material Selection	2
Baseline Property Data	8
Property Data after Environmental Exp.	16
Age-Life Predictions	17
Final Report	18

Budget: Manpower - 38 manmonths
Material - $15K
Hardware - $ 2K

<u>Facilities</u>: (and supporting test equipment)

Major Facilities - none
Supporting test equipment - $3K
Strain Meassys

/s/ <u>Stanley Podlaseck</u>
Stanley Podlaseck
Dept. 1630, Ext. 4211

Approved: /s/ <u>W. F. Barrett</u>
W. F. Barrett
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Structure SRT No. S-2

Task Title: Composite Joint Study

Statement of Problem: The between-tank skirt may be a lightweight sandwich structure with composite faces and a honeycomb core or other composite construction. It has to be attached to all metal lightweight propellant tanks. Conventional attachment methods are unsuitable because they require heavy close outs and lands and have poor load transfer characteristics for thin structure. New approaches to the joint configuration must be investigated.

Objective: To develop a joint configuration to transfer load across the skirt/propellant tank interface suitable for extra lightweight structure.

Approach: Joint configurations will be conceived to accommodate skirt structure that may be honeycomb sandwich, stiffened composite, or composite reinforced metal. Configurations will include all-bonded, bonded with mechanical fasteners, and mechanical fasteners only. Each design will go through an optimization study to achieve the lightest weight. Weight calculations will include the effect on the skirt and tanks of the requirements of the joint. Several small scale specimens of two of the most promising designs will be made and tested under simple and combined loadings. One concept will be chosen based on weight only.

Schedule: 12 month time span; Concepts complete; Optimization complete; Completion specimen fab; Completion specimen test; Final Report

Budget: 18 manmonths, $10K material

Facilities: None

/s/ Arthur Feldman
A. Feldman
Dept. 1631, Ext. 4153

Approved: /s/ W. F. Barrett
W. F. Barrett
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: SRT No. S-3

Task Title: Failure Analyses for Composite Structures

Statement of Problem: The lack of ductility in composite materials prohibits using plasticity at ultimate load in joint design. Failure analyses for bonds, joints, and fiber-matrix interfaces are crude or non-existent.

Objective: To develop failure analysis methods for composite interfaces, bonds, and joints.

Approach: Perform detail analyses of joints, etc., with refinements as necessary to achieve correlation with test results. Establish significant variables in bonds, joints, and interfaces and required levels of analysis.

Schedule: 18 months time span

Budget: 5 man years; computer time

Facilities: Large Scientific digital computer

/s/ A. A. Holston, Jr.
A. A. Holston, Jr.
Dept. 0436, Ext. 4607

Approved: /s/ R. G. Morra
R. G. Morra
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: SRT No. S-4

Task Title: Finite Elements for Composite Structures

Statement of Problem: Better analysis methods are required. The material is very brittle and unforgiving of high local stresses overlooked by simplified analyses. Furthermore, it is anisotropic and the resulting structure is inhomogeneous when it is layered. Thus, prohibiting simplified analyses.

Objective: To develop finite elements applicable to structures utilizing composite materials.

Approach: Develop finite plate and shell elements with coupling between bending and stretching, anisotropic material properties, and inhomogenity. Incorporate these elements in finite element structural analysis computer programs.

Schedule: 18 months time span

Budget: 6 man years; computer

Facilities: Large Scientific digital computer

/s/ A. A. Holston, Jr.
A. A. Holston, Jr.
Dept. 0436, Ext. 4607

Approved: /s/ R. G. Morra
R. G. Morra
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Structure SRT No. S-5

Task Title: Composite Honeycomb Assurance

Statement of Problem: Identification of fabrication anomalies and criticality in composite structures.

Objective: Determine criticality of fabrication anomalies and identify methods for nondestructive detection and evaluation.

Approach:

1. Fabricate component elements containing typical fabrication anomalies (unbonds, crushed core, marcels, wrinkles).

2. Establish nondestructive evaluation method sensitivities and test requirements. Candidate nondestructive methods include: sonics, ultrasonics, thermal, holographic and X-ray inspection.

3. Test component elements to establish criticality. Monitor by acoustic emission techniques.

4. Analyze data and determine baseline nondestructive acceptance methods and acceptance criteria.

5. Fabricate a component with interacting joints. Evaluate and status by nondestructive methods. Test component to verify acceptance criteria and interactions.

6. Repeat component evaluation cycle during structures qualification.

Schedule: 14 month time span

1. Component elements fabrication complete.
2. Component elements evaluation complete.
3. Component elements test complete.
4. Data analysis complete.
5. Component fabrication complete.
6. Component test and analysis complete.

<u>Budget</u>: 36 manmonths, $6K materials

<u>Facilities</u>: Sonic Resonance Unit, $6K

/s/ Ward D. Rummel
Ward D. Rummel
Dept. 0629, Ext. 2130

Approved: /s/ O. D. Giltner for
R. B. Davis
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Structures SRT No. S-6

Task Title: Honeycomb Core Optimization

Statement of Problem: The between-tank skirt may be a lightweight sandwich construction with honeycomb core. Before this construction can be designed for lightest weight, the core must be optimized. New materials are available which have not been used extensively in core before and present configurations may not be the most efficient for them.

Objective: To develop the most weight efficient honeycomb configuration for the sandwich construction in the between tanks skirt.

Approach: Honeycomb material in isogrid, hexagonal, and flexcore styles will be obtained of aluminum, graphite/epoxy, fiberglass/epoxy, and titanium. Appropriate ranges of wall thickness and cell size will be tested under shear and compression loads. That combination of material and geometric arrangement having the least weight and capable of carrying the applied loads will be proposed for use in the inter-tank skirt.

Schedule: 9 months time span

Budget: 15 manmonths; $6K material

Facilities: None

/s/ Arthur Feldman
A. Feldman
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Approved: /s/ W. F. Barrett
W. F. Barrett
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Tug Structure SRT No. S-7

Task Title: Lightweight Shell Structures

Statement of Problem: The high mass fraction required for Space Tug makes it necessary to minimize structural weight. This can be done by identifying general types of lightweight structures such as skirt or tank shell sections and engine and equipment support trusses, and by initiating design optimization, fabrication, and test programs early in the overall Space Tug master schedule plan. It is mandatory that materials and structural concepts considered for use in these development programs are not prejudged before they are fully evaluated for the specified design requirements.

Advances in the state-of-the-art of advanced fibrous composites in the areas of raw material processing, improved analysis methods, and fabrication techniques make materials such as graphite/epoxy and boron/epoxy leading candidates for incorporation in the design of lightweight shell structures.

Objective: A specific space structure, the Space Tug between tanks skirt, will be evaluated to determine the feasibility of using advanced fibrous composites in the design of lightweight space vehicle structure. The desirability of a fibrous composite skirt will be demonstrated by the fabrication and test of a full scale skirt. Successful structural test of the skirt structure will verify design and analysis techniques. Final selection of a fibrous composite material to be used will be made following vacuum effects testing of candidate materials. Successful completion of the proposed program should result in a skirt structure which is approximately 25 percent lighter than a skirt designed using conventional metals.

Approach: The proposed work will be divided into three phases: Phase I - Concept and Material Evaluation. Design and Analysis; Phase II - Component Fabrication and Test; and Phase III - Full Scale Skirt Fabrication and Test. The approach to be followed during each phase is outlined below.

Phase I - Concept and Material Evaluation, Design and Analysis - The skirt structure will contain one or more types of fibers, an organic matrix material and a metal. The fibers will be chosen for their strength, stiffness, magnetic and thermal characteristics, the matrix for its outgas stability and maximum temperature capability, and the metal for its bearing strength and thermal characteristics.

High modulus graphite/epoxy material has the highest stiffness/density ratio of the candidate structural materials and is therefore the leading candidate for this particular application. Long-time dimensional stability of graphite/epoxy composites, however, may not be compatible with the requirements of Space Tug. The amount of stress-relaxation combined with the possible volume change of the epoxy matrix due to low levels of degassing for long time periods is an unknown. Since the dimensional change requirements are beyond the limits of sensitivity of conventional displacement transducers and optical devices, a method incorporating the interferometric method of measuring displacement will be developed. This method will be used to measure the dimensional changes of specimens exposed to high vacuum at a variety of temperatures. Using the method of time-temperature exchange, the long-time dimensional stability of the candidate material will be predicted for the full 10-year mission.

Attachment techniques (i.e., adhesive joints) are also subject to the questions of strength and creep. Adhesive joint designs will be subjected to tests determining long-term creep and strength.

Phase II - Component Fabrication and Test - The most promising components designed during Phase I will be built to demonstrate proposed fabrication techniques. Consideration will be given to mandrel design, lamination methods, vacuum bagging technique, and cure cycle to assure high quality, defect-free final components. Fabrication methods will include conventional metal machining, composite lamination, filament winding and adhesive bonding.

The components will be structurally tested to determine strength and stiffness.

Phase III - Full Scale Skirt Fabrication and Test - Successful completion of the Phase II subsize panel program will be followed by fabrication and test of a 10-foot diameter, 6-foot high cylinder to be instrumented and tested in combined torsion and axial compression.

Schedule: 22 months time span

Budget: 15,000 manhours; $20K material and hardware

Facilities: None

/s/ J. Parham

J. Parham
Dept. 0436, Ext. 3773

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Materials SRT No. S-8

Task Title: Fracture Toughness Investigation of Thin Gage Titanium 6Al-4V

Statement of Problem: In order to do a thorough fracture control analysis on the main propellant tanks, data is needed in the gages being considered (0.018" min.). There is very little data available in these proposed gages. Also toughness data will be determined for premium grade alloy that has recently become available.

Objective: To develop fracture toughness data for Ti-6Al-4V in several gages (0.018" to 0.054"). This includes K_{IC}, K_{TH}, and da/dN data for both parent and weld metal. Both regular grade and premium grade material will be evaluated.

Approach:

1. Develop specimen configuration and flawing techniques.
2. Run plane-strain toughness (K_{IC}) tests on several gages.
3. Determine K_{TH} values for various thicknesses looking at N_2O_4, A-50, and MMH.
4. Run da/dN specimens.
5. Make all the data available for use with existing and proposed computer programs.

Schedule: 18 month time span

Budget: Manpower - 50 manmonths
Material - $30K
Computer Time - 20 hrs.

Facilities: None

/s/ D. A. Bolstad

D. A. Bolstad
Dept. 0436, Ext. 2434

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Propulsion SRT No. S-9

Task Title: Composite Helium Pressurization Vessel

Statement of Problem: Pressurization of the propulsion system requires helium holders of 8 cu. ft. capacity with an operating pressure of 3500 psi. Significant weight can be saved if these vessels are built of composite overwrapped on a metal liner. However, vessels this size have not been built before of the primary candidate materials, that is, graphite/epoxy or PRD-49/eposy.

Objective: To design and develop the manufacturing process for a composite overwrapped pressure vessel for the helium holders on Tug.

Approach: An existing computer program will be used to design the vessel in both graphite/epoxy and PRD-49/epoxy using published material properties. The most efficient design will be built and proof tested. Results of a companion effort on developing a metal liner will be used to provide the necessary liner. If that technology is not available at the appropriate time, an elastomeric liner will be used. An elastomeric liner is sufficient to demonstrate the structural capability of the overwrap, but not the long time storage capability. If a metallic liner is available, then a prototype vessel will be built and tested to failure or 100 cycles at the operating pressure with dwell times corresponding to mission requirements.

Schedule: 9 months time span

Budget: 12 manmonths, $25K material

Facilities: None

/s/ Arthur Feldman
A. Feldman
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Approved: /s/ W. F. Barrett
W. F. Barrett
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Structures - Pressurization System SRT No. S-10

Task Title: Crack Detection Sensitivities for Thin Gage Tank Liners and Joints

Statement of Problem:

Objective: To determine the threshold crack detection sensitivities for thin gage tank liners and joints.

Approach:

1. Fabricate test specimens containing cracks of known sizes.

2. Evaluate specimens by X-ray, ultrasonic, eddy current, penetrant and holography to determine detection sensitivity and reliability.

3. Proof test specimens and monitor by acoustic emission.

4. Fracture specimens and analyze data.

5. Fabricate subscale overwrapped tanks containing known cracks.

6. Evaluate tanks by X-ray, ultrasonic, eddy current and holography to determine detection sensitivities.

7. Proof test tanks and monitor by acoustic emission to crack criticality.

8. Analyze data.

Schedule: 18 month time span

1. Specimen fabrication
2. Nondestructive evaluation
3. Proof test, fracture and data analysis
4. Subscale tank fabrication
5. Nondestructive evaluation of tanks
6. Proof test, fracture and data analysis

<u>Budget</u>: 24 manmonths, $4K material

<u>Facilities</u>:

Eddy current flow
Detector for low conductivity
Materials - $5K

/s/ <u>W. D. Rummel</u>
W. D. Rummel

Approved: /s/ <u>O. D. Giltner for</u>
R. B. Davis
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Structures SRT No. S-11

Task Title: Analytical Methods for Composite Pressure Vessels.

Statement of Problem: Composite pressure vessels with metal liners offer significant weight savings for high pressure applications. However, available analysis methods are crude and do not correlate well with test data. They use "netting" analysis, empirical liner buckling, bi-linear stress-strain, etc.

Objective: To develop improved analyses methods for composite pressure vessels with liners.

Approach: Develop analysis for buckling of overwrapped liner. Formulate analysis of composite pressure vessels using shell theory, plasticity theory for liner, and anisotropic failure criteria for overwrap. Develop computer program to implement analysis.

Schedule: 18 month time span

1. Buckling analysis
2. Improved pressure vessel analysis
3. Computer program

Budget: 4 man years
Computer time

Facilities: Large Scientific Digital Computer

/s/ A. Holston, Jr.
A. Holston, Jr.
Dept. 0436, Ext. 4607

Approved: /s/ R. G. Morra
R. G. Morra
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Structures (Propulsion) SRT No. S-12

Task Title: Liner Bonding for Helium Pressurization Vessel

Statement of Problem: A composite helium pressurization vessel for the propulsion system requires a metal liner to provide the low leak rates associated with long time storage. Weight efficiency demands that this liner be thin, which makes it susceptible to buckling upon vessel unloading. Compression stresses can be induced on unloading if there is any yielding during pressurization. Buckling on each unloading cycle will reduce the cyclic life as it increases the probability of cracking of the liner material. The only way to prevent buckling is to bond the liner well enough to the overwrap so that the overwrap provides support in the event of compression in the liner. The bond line is subjected to a combination of shear and tensile stresses when there is a tendency for the liner to buckle.

Approach: A specimen configuration will be developed to provide an appropriate stress state in the bond line between a thin sheet of metal, probably aluminum, and a piece of graphite/epoxy composite. The stress state to be modelled is that which exists when the liner is subjected to compression during depressurization of the vessel. Specimens will then be made using several different adhesives, including the resin system in the composite, and after several different cleaning treatments of the liner material. Fatigue tests will be performed to operating pressure for at least 100 cycles. That combination of adhesive and cleaning technique with the best performance will be incorporated into subscale vessels for cyclic testing under internal pressure.

Schedule: 11 month time span

Specimen Design & Fixture Design
Specimen Tests
Subscale Vessels Fabricated
Subscale Vessel Tests
Final Report

Budget: 12 manmonths, $4K material

Facilities: None

/s/ Arthur Feldman
A. Feldman
Dept. 1631, Ext. 4153

Approved /s/ W. F. Barrett
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Structures (Propulsion) SRT No. S-13

Task Title: Liner Manufacturing for the Helium Pressurization Vessel

Statement of Problem: A composite helium pressurization vessel for the propulsion system requires a metal liner to provide the low leak rates associated with long time storage. Vessel efficiency demands that this liner be thin. A manufacturing process must be developed to provide 25 to 30 inch diameter metal vessels in an oblate spheroid configuration with a wall thickness of 6 to 20 mills. Leak proof welds to heavy end bosses must be incorporated.

Objective: To develop a manufacturing process for the metal liner of the composite helium pressurization vessel.

Approach: The need for light weight supports the choice of aluminum for the vessel liner material. Various welding techniques and configurations such as roll seam, electron beam, butt, butt with doublers, lap, etc., will be tried on small pieces of the liner material. The promising approaches will then be used to make one or more full scale liners.

Schedule: 8 month time span

Budget: 13 manmonths, $4K material

Facilities: Electron Beam Welder

/s/ Arthur Feldman
A. Feldman
Dept. No. 1631, Ext. 4153

Approved: /s/ W. F. Barrett
W. F. Barrett
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Structures - Pressurization Tank SRT No. S-14

Task Title: Composite Overwrapped Tank Assurance

Statement of Problem: Identification of fabrication anomalies and criticality in composite overwrapped tanks.

Objective: Determine criticality of fabrication anomalies and identify methods for nondestructive detection, characterization and evaluation of composte overwrapped tanks.

Approach:

1. Fabricate subscale tanks containing fabrication anomalies. (unbonds, low strength, broken fibers)
2. Establish sensitivities of nondestructive evaluation methods. Methods include: sonics, ultrasonics, thermal holographic and x-radiographic techniques.
3. Test subscale tanks to established criticality of anomalies. Monitor test by acoustic emission.
4. Analyze data and determine baseline nondestructive acceptance methods and acceptance criteria.
5. Fabricate prototype tank containing known anomalies.
6. Evaluate and status tank by nondestructive evaluation methods. Monitor and analyze proof test by acoustic emission.

Schedule: 11 month time span

1. Subscale tank fabrication
2. Nondestructive evaluation
3. Subscale tank test
4. Data analysis
5. Prototype tank analysis

Budget: 36 manmonths, $4K materials, $10K tanks

Facilities: none

/s/ Ward D. Rummel

Ward D. Rummel
Dept. 0629, Ext. 2130

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Structures (Propulsion) SRT No. S-15

Task Title: Propellant Behavior in Elastic Tanks

Statement of Problem: Most of the present methodology is not capable of handling propellant slosh and tank deformation due to propellant forces in slanted or asymmetric tanks. The problem is aggrevated if baffles are installed. Because of thin skin gauges of the tank walls and domes, the fluid/structural interaction is of considerable importance in defining the loads on the structures and the propellant motion for stability analyses.

Objective: Develop an efficient computer program compatible with the finite element approach to the solution for the natural modes

Approach: Review present approaches available, investigate their applicability to the solution of this problem and propose the most efficient approach modified as required.

Schedule: 16 month time span

Phase I Approach Selection
Phase II Program Setup and Coding
Phase III Demonstration Problems

Budget: 20 manmonths engineering manpower
10 hrs CDC 6500 or equivalent computer time

Facilities: CDC 6500, Univac 1108 or IBM 360 Mod. 95 or equiv.

/s/ G. Morosow
G. Morosow
Dept. 0433, Ext. 3956

Approved: /s/ R. G. Morra
R. G. Mora
Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Structures SRT No. S-16

Task Title: Analytical Method for Docking and Capture of Elastic Spinning Satellites

Statement of Problem:

Objective: Computer programs were developed during the Skylab program to handle the dynamics and the ensuing motion of two elastic bodies. This approach must be extended to handle a case where one body is spinning.

Approach: Review available approaches and computer programs, select the most general one and extend to handle the spinning case.

Schedule: 16 month time span

Phase I Method Definition
Phase II Computer Program Development
Phase III Demonstration and Documentation

Budget: 30 manmonths, 15 hrs. CDC 6500 or equivalent

Facilities: None

/s/ G. Morosow
G. Morosow
Dept. 0433, Ext. 3956

Approved: /s/ R. G. Morra
R. G. Morra
Department Manager

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APPENDIX A

4.5 MANUFACTURING

(M-1 thru M-4)

MANUFACTURING SRT

NUMBER	TITLE & DESCRIPTION	MM/$	SCHEDULE	OPTION
M-1	Improved Weld Technology - Domes and Barrels 1. Segments (1/8) - Tool - Fab 2. Weld Land Width/Thickness - Geometry - Filler - Weld - Stress Relieve (1100^{o}F) - Evaluation 3. Land Reduction After Weld - Geometry - Weld - Stress Relieve - Reduce - Material - Evaluation 4. Intersection Configuration - Geometry - Weld - Stress Relieve - Evaluation 5. Repair - (Land Requirements) - Preparation - Weld - Evaluation 6. Penetrations-(Land/Configuration) - Geometry - Stress Relieve - Evaluation	16MM/$10K	18 Mo.	All
M-2	Composite Structure Development Note: Tasks 1 and 2 of M-2 will be joint efforts with Engineering Development and Advanced Manufacturing Technology in regard to Tasks S-1, S-4, S-28, S-29, S-21 and S-34 to develop techniques which can be translated into actual, cost-effective manufacturing techniques.	19MM/$10K	18 Mo.	All

NUMBER	TITLE & DESCRIPTION	MM/$	SCHEDULE	OPTION
M-2 (Cont)	1. Material - Select Candidates - Evolve Layup Technique - Fab. Specimens - Evolve Inspection Techniques - Test and Analyze Results - Select Material 2. Geometry - Establish Preliminary Joint Configuration - Evolve Inspection Techniques - Fabricate Segment Models & Test - Document Layup Technique (Preliminary Process) - Document Tooling Approach (Report) 3. Modification and Repair - Fab. Test Specimens with Defects - Inspect - Test - Evaluation - Fab. Segment Models with Defects - Inspect - Test - Evaluation - Repair Segment Models Above - Inspect - Test - Evaluate and Report - Inspection Process and Repair Technique			
M-3	One-Piece Dome Fabrication - 2219 Aluminum and 6-4 Titanium 1. Vendor Capability Evaluation - Spinning - Explosive Forming - Bulge Forming - Select one 2. Development Contract (Sub Scale) - Design Parameters - Die Design and Fabrication - Development Pieces & Evaluation - Cost Study & Production Study - Make full-scale Prototypes	36MM/15K	18 Mo.	3

NUMBER	TITLE & DESCRIPTION	MM/$	SCHEDULE	OPTION
M-3 (Cont)	3. Development Contract Machining - Select Vendors and Provide for Transportation - Tolerance Control and Contour Control - Select Time of Heat Treatment for Machining Sequence Interruption - Extrapolate to Full Size - Make Full Size 4. Fabrication - Develop Final Sequence Based on Forming & Machining, Chem. Mill and Conventional Machining - Develop Physical Handling and Tool Concepts			
M-4	Screen Surface Tension Device - Development and Incorporation into A Tank Note: Tasks 1 and 2 of M-4 will be joint efforts with Engineering Development and Advanced Manufacturing Technology in regard to Tasks P-6, P-7, P-12, P-15, and P-16 to develop techniques which can be translated into actual, cost-effective manufacturing techniques. 1. Screen Device - Sample Screen Material to Develop Weld Parameters - Sample Screen Material for Tensile Specimens - Sample Screen Material for B/P Specimens. - Resistance Weld Para Dev. Four Screen Tubes - Screen to Non-Screen Joining (Samples) - Screen to Non-Screen Joining (Interfaces) - Develop Sample Screen Trap - Develop Assy. Techniques Two Complete Screen Devices	11MM/$10K	18 Mo.	All

NUMBER	TITLE & DESCRIPTION	MM/$	SCHEDULE	OPTION
M-4 (Cont)	2. Tank Construction and Installation - Develop Weld Schedules in Chamber - Out of Chamber - Fusion Weld Tensile Specimens - Develop Tank to Dome Weld Specimens - Develop Tank Weld Tooling Philosophy - Develop Assy. Techniques - Two Complete Tanks - Radiographic Testing and NDT - Proof Testing			
	3. Manufacturing Tooling Development and Definition - Mandrels for Screen Tube Forming - Electrodes for Screen Tube Welding - Tooling to Fabricate Outlet Screen Trap - Tooling for Positioning Screen Trap - Details for Welding - Detail Bubble Point Test Fixture - Assembly Bubble Point Test Fixture - Weld Tooling for Outlets in Dome Caps - Internal/External Dome to Barrel Weld - Tooling - Adapter Tooling for Close-Out Weld - Modification of Titanium Weld Chamber for Circumerentia Welding (Blue Goose) - 500 Watt Second Capicitor Discharge Welder			

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APPENDIX A

4.4 THERMAL

(T-1 & T-2)

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Thermal Control SRT No. T-1

Task Title: Reusability of Multi-Layer Insulation (MLI)

Statement of Problem: The reusability of MLI must be established for its application on Tug. The number of use cycles affects refurbishment time, cost, and Tug weight.

Objective: 1) Describe use cycle and identify the most injurious environments; 2) Setup and perform relative performance tests, with these environments, for candidate MLI materials; 3) Fabricate MLI blankets from best candidate materials and perform initial thermal conductance test, and 4) Expose MLI blankets to 4 blocks of 25 use cycles and measure thermal conductance after each block.

Approach: Define the thermal conductance degradation curve vs number of cycles. Two configurations will be tested: a) large MLI blanket, and b) MLI wrapped ACS propellant line.

Schedule:

Completion objective:	1) 3 mo. ATP	3) 10 mo. ATP
	2) 5 mo. ATP	4) 18 mo. ATP

Budget: 48 manmonths, Engr., 24 manmonths Lab. Techs., $15K Material

Facilities:

Environment Chamber
Vacuum Chamber
Dynamic Test Facility
Large Cryogenic Calorimeter
Engine Bell Simulator

/s/ R. O. Hartung
R. O. Hartung
Dept. 0444, Ext. 4203

Approved: /s/ J. H. Kidd for R. J. Farrell

Department Manager

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Thermal Control SRT No. T-2

Task Title: Reusability of Tug Coatings

Statement of Problem: Thermal control coating life must be established for Tug application. Reusability and refurbishment qualities will affect Tug turnaround time and operational costs. Poor coating durability could actually require additional Tugs in order to allow for extensive refurbishment times. Notice that previous coating development has been for one time application.

Objective: 1) Select candidate coatings. 2) Design an accelerated life cycle test to simulate Tug conditions. 3) Determine candidate performance by test. 4) Develop refurbishment techniques for compatibility with Tug operations requirements.

Approach: Currently available coatings will be used for candidate selection. Already available life data relating to certain segments of the test cycle may be available and the test cycle will be modified accordingly.

Schedule:

Objective:	1)	4 mo. ATP	3)	18 mo. ATP
	2)	5 mo. ATP	4)	18 mo. ATP

Budget:

48 manmonths Engr.
28 manmonths Techs.
$25K material

Facilities:

Environment Chamber
Vacuum Chamber
Reflectometer
Emissometer
Dynamic Test Facility

/s/ R. O. Hartung
R. O. Hartung
Dept. 0444, Ext. 4203

Approved: /s/ J. H. Kidd for R. J. Farrell

Department Manager

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4.6 FLIGHT OPERATIONS

(F-1)

SPACE TUG SUPPORTING RESEARCH & TECHNOLOGY

Subsystem: Flight SRT No. F-1

Task Title: Operability Analysis

Statement of Problem: Analyses of this nature have been performed too late on previous programs and therefore have been ineffective in achieving optimum operability and compatibility with ground system (networks).

Objectives/Approach:

1. Candidate Tug system designs will be evaluated for operability during the design development stages so that appropriate modifications can be readily incorporated. Recommendations will be made to improve ease of monitoring and control and enhance flexibility for crew (Shuttle) and ground (network) operations as applicable. Interfaces with the orbiter and the payloads will be assessed for monitoring and control functions.

2. Flight operations planning and handling/processing requirements of the on-board systems will be compared with both NASA and DOD ground system capabilities to verify compatibility. Alternatives will be considered for maintaining an operational network during transition from present programs to the Shuttle era and tradeoffs affecting expansion of STC facilities and network for Shuttle Orbiter usage from safety and compatibility aspects.

3. Crew roles will be developed and optimized for the following functions:

   a) Tug systems checkout prior to release from Shuttle
   b) Payload placement/retrieval
   c) Rendezvous and docking of stages or with Shuttle

   This role is important to provide flexibility for ease of monitoring and control and to provide for human factors aspects to be incorporated early in the design for cost effectivity.

   A plan will be generated for use of mock-ups, trainers and simulators. Soft mock-ups have been used effectively in early phases of previous programs and the use of Crew Stations trainers and docking simulators are considered cost effective by reducing crew training requirements for the numerous tugs envisioned.

Schedule: 18 months

Budget:
a) 135 man months
b) 120 man months
c) 162 man months

/s/ B. S. King
B. S. King
Dept. 0492, Ext. 4141

Approved: /s/ T. Sulmeisters
T. Sulmeisters, Chief
Flight Operations

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APPENDIX B

DETAILED RELIABILITY ANALYSIS WORKSHEETS, ANALYSIS ASSUMPTIONS AND EXPLANATIONS

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APPENDIX B

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B1.0 ANALYSIS ASSUMPTIONS

B1.1 The basic analysis was done on two basic missions: (1) the 6 day roundtrip (deploy/retrieve) geostationary mission; and, (2) the 2 day deploy geostationary mission. All other mission reliabilities have been extrapolated from the above analysis at the subsystem level.

B1.2 The analysis includes, for each mission, an additional period of 24 hours to account for the time which may be spent in the orbiter; after orbiter orbit insertion.

B1.3 The following mission assumptions have been made for the reliability analysis.

a. Option 1 - Geostationary Deployment Mission

   Duration - 60 hours (including 24 hours in the orbiter)
   Number of main engine burns - 6

b. Planetary Deployment Mission, Options 1, 2 and 3

   Duration - 60 hours (including 24 hours in the orbiter)
   Number of main engine burns - 6

c. Polar Deployment Mission, Options 1, 2 and 3

   Duration - 38 hours (including 24 hours in the orbiter)
   Number of main engine burns - 6; Drop Tank Life (Stage and ½) - 32 hours

d. Mid-inclination Deployment Mission, Options 1, 2 and 3

   Duration - 60 hours (including 24 hours in the orbiter)
   Number of main engine burns - 6; Drop Tank Life (Stage and ½) - 32 hours

e. High Energy Planetary Mission (Expendable mode), Options 1, 2 and 3

   Duration - 31 hours (including 24 hours in the orbiter)
   Number of main engine burns - 2; Drop Tank Life (Stage and ½) - 25 hours

f. Options 2 and 3 - Geostationary Deployment Mission

   Duration - 72 hours and 168 hours (each including 24 hours in the orbiter)
   Number of main engine firings - 6 (in each case); Drop Tank Life - 32 hours

g. Options 2 and 3 - Dedicated Deploy Mission

   Duration - 126 hours (including 24 hours in the orbiter)
   Number of main engine firings - 6; Drop Tank Life (Stage and ½) - 48 hours

h. Options 2 and 3 - Geostationary Roundtrip (Deploy/Retrieve) Mission

Duration - 72 hours and 168 hours (each including 24 hours in the orbiter)
Number of main engine firings - 8; Drop Tank Life (Stage and ½) - 32 hours

i. Options 2 and 3 - Polar Deploy/Retrieve Mission

Duration - 43 hours (including 24 hours in the orbiter)
Number of main engine firings - 8; Drop Tank Life (Stage and ½) - 32 hours

j. Options 2 and 3 - Dedicated Retrieval Mission

Duration - 60 hours (including 24 hours in the orbiter)
Number of main engine firings - 8; Drop Tank Life (Stage and ½) - 35 hours

k. Options 2 and 3 - Mid-inclination Deploy/Retrieve Mission

Duration - 72 hours (including 24 hours in the orbiter)
Number of main engine firings - 8; Drop Tank Life (Stage and ½) - 32 hours

B1.4 An environmental factor of one (1) had been used throughout the analysis for all subsystems except:

a. Controls Subsystem - Used and environmental factor of fifty (50) - since that subsystem operates only during main engine firings.

b. Engines - Although no specific environmental factor has been applied to the analysis of the engines it is believed that the data used in the analysis includes an environmental factor greater than one (1) as the data used was compiled specifically for Rocket engines.

The rationale for using one (1) as an environmental factor is that all but 50 minutes of each mission is quiescent (including boost).

B1.5 Specific assumptions have been used in the various subsystem analyses and those assumptions can be found in the paragraphs which follow for each subsystem.

B2.0 DETAILED ANALYSIS WORKSHEETS, ASSUMPTIONS, EXPLANATIONS

B2.1 Structures

STRUCTURE

The Structure System does not lend itself to a classical Reliability Analysis. Designing to required factors of safety, rigorous stress, loads and dynamic analysis, plus a structural test program leads to the high reliability required. From the analytical viewpoint it is considered to have a reliability of 1-.

SUBSYSTEM: STRUCTURE

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
		NOT APPLICABLE		

B2.2 Electrical Power

Solar Array Subsystem Reliability Analysis Assumptions:

1. Two solar panels - Each sized to complete mission if other fails

2. Solar panels furled (closed) during engine firings, docking, and Tug/Shuttle deployment retrieval - estimate 6 hrs. total; therefore, 165 AH battery operates 6 hrs., 25 AH battery operates 2500 seconds (OME engine firing time + ordnance time $\sim$5 sec.)

3. Charger operates approximately 40% of mission time

4. 180 rows of 100 cells in each solar panel in parallel. Mission is completed satisfactorily on 175 rows still operating, i.e., 5 failures allowed. Therefore, the reliability for each panel is obtained by binomial expansion of the reliability of 100 cell in series, 175 of 180 rows required.

SUBSYSTEM: Solar Array Subsystem

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY	
		7 Day Mission	3 Day Mission	7 Day	3 Day	7 Day	3 Day
Solar Array Orientation Mechanism							
Gimbal	2.5 —— HR	50 HR	25 HR	$.0_3125$	$.0_4625$		
Gimbal	2.5 —— HR	50 HR	25 HR	$.0_3125$	$.0_4625$		
Motor	.3 —— HR	50 HR	25 HR	$.0_4150$	$.0_5750$		
Motor	.3 —— HR	50 HR	25 HR	$.0_4150$	$.0_5750$		
Cabling	.02 —— HR	168 HR	72 HR	$.0_5336$	$.0_5144$		
Connectors	.04 —— HR	168 HR	72 HR	$.0_41344$	$.0_5576$		
				$.0_32968$	$.0_31472$	.99970	.99985
Power Generation							
Solar Cell (100)	.01 —— HR	168 HR	72 HR	$.0_3168$	$.0_4720$		
Cell Bond (100)	.001 —— HR	168 HR	72 HR	$.0_4168$	$.0_5720$		
Cell Interconnection	.001 —— HR	168 HR	72 HR	$.0_4168$	$.0_5720$		
				$.0_32016$	$.0_48640$	.99979	.99991
Cabling/ Connectors (180)	.022 —— HR	168 HR	72 HR	$.0_36719$	$.0_3288$	.99933	.99972
Unfolding Mechanism		Operates ≈ 6 minutes at each engine burn -					
		8 Burns	6 Burns				
Roller	3.0 —— HR	50 Min.	40 Min.	$.0_525$	$.0_52$		
Drive Motor	.3 —— HR	50 Min.	40 Min.	$.0_625$	$.0_62$		
Latch	5. —— CYCLE	10 Cycles	8 Cycles	$.0_450$	$.0_44$		
Release	5. —— Cycle	10 Cycles	8 Cycles	$.0_450$	$.0_44$		
				$.0_31027$	$.0_4822$	8 BURNs .99989	6 BURNs .99991

THE RELIABILITY OF POWER GENERATION IS THE PRODUCT OF THE RELIABILITY OF ONE ROW OF SOLAR CELLS (R = .99979) EXPANDED BINOMIALLY (175 ROWS OF 180 ROWS REQUIRED) TIMES THE RELIABILITY OF THE CABLING/CONNECTORS (R = .99933)

BINOMIAL EXPANSION RELIABILITY OF .99979 YIELDS .99999 OR BETTER

∴ RELIABILITY FOR POWER GENERATION = .99933 X .99999
= .99932 FOR 7 DAYS

SIMILARLY R = .99971 FOR 3 DAYS

SUBSYSTEM: Solar Array Subsystem

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY	
Power Storage and Charging		7 Day Mission	3 Day Mission	7 Day	3 Day		
A. Charger*		70 Hrs for each component	30 Hrs for each component .0				
4 Transistors	.1 — HR			$.0_4 28$	$.0_4 12$		
2 Power Diodes	.2 — HR			$.0_4 28$	$.0_4 12$		
8 Capacitors	.01 — HR			$.0_5 56$	$.0_5 24$		
40 Resistors	.04 — HR			$.0_3 112$	$.0_4 480$		
2 Coils	.014 — HR			$.0_5 196$	$.0_6 84$		
Cabling	.02 — HR			$.0_5 336$	$.0_5 144$		
3 Relays	.250 — HR			$.0_4 525$	$.0_4 225$	7 Day	3 Day
				$.0_3 23142$	$.0_4 8838$	.99977	.99991
			Non-Operate Factor	$.0_4 23142$	$.0_5 8838$	.99974	.99990
B. Storage							
165 AH Battery (20 cells)	5.6/Cell — HR	6 HR	6 HR	$.0_3 672$		.99932	
25 AH Battery (20 cells)	5.6/Cell — HR	1 HR	1 HR	$.0_3 112$		.99988	
* Representative Piece Parts							
Power Distribution							
Motor Driven Switch	.5 — HR	168 HR	72 HR				
Bus	.02 — HR	168 HR	72 HR	7 Day	3 Day		
	$.57/10^6$ HR	168 HR	72 HR	$.0_4 8736$	$.0_4 3744$		

SUBSYSTEM: Solar Array Subsystem

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY	
		7 Day Mission	3 Day Mission	7 Day	3 Day		
(37) Remote Power Controller:							
(1) Transistor	.1 ——— HR	168	72				
(9) SCR	.6 ——— HR	168	72				
(9) Diodes	.03 ——— HR	168	72				
(9) Resistors	.003 ——— HR	168	72				
	37 X .773/10^6 HR	168 HR	72 HR	$.0_{2}3556$	$.0_{2}19527$		
(37) Load Bus	.02 ——— HR	168 HR	72 HR	$.0_{3}1243$	$.0_{4}53280$		
(37) Circuit Breakers:	.733/10^6 HR	168 HR	72 HR	$.0_{2}4556$	$.0_{2}19527$		
(Components Similar to Remote Power Controllers)		Total for Power Distribution		$.0_{2}9323$	$.0_{2}39961$	.99073	.99600
<u>Power Regulation</u> Regulator (Components Similar to Charger)	Same failure rate as charger failure rate = 3.378/10^6	168 HR	72 HR	$.0_{3}5675$	$.0_{3}2432$	.99943	.99976

Battery Power
Electrical Subsystem
SUBSYSTEM: AV-9 (4)

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Provide Source Energy 165 AH Battery (20 Cells)	5.6/cell HR	60 HR	$.0_2 672$	.99330
Distribution Hardware (Same as AV-I Configuration)	EXTRAPOLATED FROM 72 HOUR MISSION			.99668

B2.3 Communications

SUBSYSTEM: Communications

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY	
		7 Day Mission	3 Day Mission	7 Day	3 Day	7 Day	3 Day
Hi Gain Atenna Gimbals & Coaxial Cable							
Antenna	.7 — HR	168 HR	72 HR	$.0_{3}1176$	$.0_{4}504$		
Gimbal*	2.5 — HR	50 HR	25 HR	$.0_{3}125$	$.0_{4}625$		
Gimbal*	2.5 — HR	50 HR	25 HR	$.0_{3}125$	$.0_{4}625$		
Gimbal Motor*	.3 — HR	50 HR	25 HR	$.0_{4}150$	$.0_{5}75$		
Gimbal Motor*	.3 — HR	50 HR	25 HR	$.0_{4}150$	$.0_{5}75$		
Coaxial Cable	.02 — HR	168 HR	72 HR	$.0_{5}336$	$.0_{5}144$		
				$.0_{3}40096$	$.0_{3}19184$	.99960	.99981
*Assume Gimbals/Motors operate 1/3 of the time.							
Switch	.05 — HR	168 HR	72HR	$.0_{5}84$	$.0_{5}36$	.99999	.99999
Diplexer	.131 — HR	168 HR	72 HR	$.0_{4}22008$	$.0_{5}9432$	.99997	.99999
Switch (And	.05 — HR	168 HR	72 HR	$.0_{5}84$	$.0_{5}36$	.99999	.99999
Cabling	.02 — HR	168 HR	72 HR	$.0_{5}336$	$.0_{5}144$	.99999	.99999
Receiver							
Equivalent of							
75 IC Circuits	.03 — HR	168 HR	72 HR	$.0_{3}378$	$.0_{3}162$		
3 Connectors	.04 — HR	168 HR	72 HR	$.0_{4}2016$	$.0_{5}864$		
				$.0_{3}39816$	$.0_{3}17064$	.99960	.99983
OR							
10 ICs	.03 — HR	168 HR	72 HR	$.0_{4}504$	$.0_{4}216$		
50 Transistors	.01 — HR	168 HR	72 HR	$.0_{4}840$	$.0_{4}360$		
100 Resistors	.003 — HR	168 HR	72 HR	$.0_{4}504$	$.0_{4}216$		
100 Capacitors	.003 — HR	168 HR	72 HR	$.0_{4}504$	$.0_{4}216$		
30 Diodes	.03 — HR	168 HR	72 HR	$.0_{3}151$	$.0_{4}648$		
3 Connectors	.04 — HR	168 HR	72 HR	$.0_{4}151$	$.0_{5}648$		
				.0004013	$.0_{3}17208$	.99960	.99983

SUBSYSTEM: Communications

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY	
		7 Day Mission	3 Day Mission	7 Day	3 Day	7 Day	3 Day
Transmitter							
Equivalent of							
50 ICs	.03 —— HR	168 HR	72 HR	$.0_3250$	$.0_3108$		
2 Connectors	.04 —— HR	168 HR	72 HR	$.0_5672$	$.0_5288$		
Cabling	.02 —— HR	168 HR	72 HR	$.0_5336$	$.0_5144$		
				$.0_326008$	$.0_311232$	.99973	.99988
OR							
Transmitter							
71 ICs	.03 —— HR	168 HR	72 HR	$.0_43528$	$.0_41512$		
35 Transistors	.01 —— HR	168 HR	72 HR	$.0_4588$	$.0_4252$		
70 Resistors	.003 —— HR	168 HR	72 HR	$.0_43528$	$.0_41512$		
70 Capacitors	.003 —— HR	168 HR	72 HR	$.0_43528$	$.0_41512$		
25 Diodes	.03 —— HR	168 HR	72 HR	$.0_3126$	$.0_454$		
2 Connectors	.04 —— HR	168 HR	72 HR	$.0_41344$	$.0_5576$		
				.000210	$.0_490$	.99979	.99991
Amplifier							
Equivalent of							
35 ICs	.03 —— HR	168 HR	72 HR	$.0_3176$	$.0_4756$		
2 Connectors	.04 —— HR	168 HR	72 HR	$.0_41344$	$.0_5576$		
				$.0_318944$	$.0_48136$	.99981	.99991
OR							
4 ICs	.03 —— HR	168 HR	72 HR	$.0_42016$	$.0_5864$		
15 Transistors	.01 —— HR	168 HR	72 HR	$.0_4252$	$.0_4108$		
30 Resistors	.003 —— HR	168 HR	72 HR	$.0_41512$	$.0_5648$		
30 Capacitors	.003 —— HR	168 HR	72 HR	$.0_41512$	$.0_5648$		
10 Diodes	.03 —— HR	168 HR	72 HR	$.0_4504$	$.0_4216$		
5 Transformers	.015 —— HR	168 HR	72 HR	$.0_4126$	$.0_554$		
Cabling	.02 —— HR	168 HR	72 HR	$.0_5336$	$.0_5144$		
2 Connectors	.04 —— HR	168 HR	72 HR	$.0_41344$	$.0_5576$		
				$.0_31554$	$.0_4666$	.99984	.99993

SUBSYSTEM: Communications

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY	
Interconnections		7 Day Mission	3 Day Mission	7 Day	3 Day	7 Day	3 Day
10,000 Interconnections	.0005 HR	168 HR	72 HR	.00084	.00036	The reliability of interconnections is to be divided between the XMTR, RECEIVER, and AMPLIFIER	
						.99916 or .99979 /Box	.99964 or .99991 /Box

B2.4 Controls

Main Engine Gimbal Actuation (Controls) Analysis Assumptions:

1. Operating time on control actuator is the burning time for the main engine. Burn times are:

   OME Engine - 1 Stage Vehicle - 2,500 seconds
   & Stage and a Half

   Class I and Uprated OME Engine - 1 Stage Vehicle -
   1,600 seconds & Stage and a Half

2. Apply an environmental factor to failure rates due to engine environment (50).

SUBSYSTEM: MAIN ENGINE GIMBAL ACTUATION

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME	RELIABILITY
Provide Main Engine Gimbal Actuation					
Integrated Actuator:					
Reservoir	1.5 —— Hr	2500 sec	1600 sec		
Motor/Pump	14.0 —— Hr	"	"		
Actuator	12.5 —— Hr	"	"		
Lines/Fittings	.20 —— Hr	"	"		
*Servo Amp.	24.0 —— Hr	"	"		
SServo Valve	7.0 —— Hr	"	"		
Filter	.3 —— Hr	"	"		
By Pass Valve	6.0 —— Hr	""	"		
Limit Valves	7.0 —— Hr	"	"		
	$72.5/10^6$ Hr X 50 for Environmental factor (Engine Loads)			2500 sec = $.0_2251735$ 1600 sec = $.0_2161111$	R_{2500}=.99749 R_{1600}=.99839
*MIL HANDBOOK 217A					

B2.5 Data Management

SUBSYSTEM: Data Management Subsystem RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY **	
		7 Day	3 Day	7 Day	3 Day	7 Day	3 Day
Co. P. Processor							
200 ICs	.03 —— HR	168 HR	72 HR	.001008	.000432	.99899	.99957
200 ICs	.02 —— HR	168 HR	72 HR	.000672	.000288	.99932	.99971
Cabling & -	.020 —— HR	168 HR	72 HR	$.0_5 3360$	$.0_5 144$	.99999	.99999
Connectors - (Five)	.040 —— HR	168 HR	72 HR	$.0_4 336$	$.0_4 144$	.99997	.99998
Memory							
320 ICs	.03 —— HR	168 HR	72 HR	.0016128	.0006912	.99839	.99931
	.02 —— HR	168 HR	72 HR	.001075	.0004608	.99893	.99954
Cabling	.020 —— HR	168 HR	72 HR	$.0_5 336$	$.0_5 144$	.99999	.99999
Connectors (Six)	.040 —— HR	168 HR	72 HR	$.0_4 4032$	$.0_4 1728$	.99996	.99998
CDTC Processor							
20 ICs	.03 —— HR	168 HR	72 HR	$.0_3 1008$	$.0_4 432$	.99990	.99996
	.02 —— HR	168 HR	72 HR	$.0_4 672$	$.0_4 288$	.99993	.99997
280 ICs	.03 —— HR	168 HR	72 HR	.0014112	.0006048	.99859	.99939
	.02 —— HR	168 HR	72 HR	.0009408	.0004032	.99906	.99960
Cabling	.020 —— HR	168 HR	72 HR	$.0_5 336$	$.0_5 144$	.99999	.99999
Connectors	.040 —— HR	168 HR	72 HR	$.0_4 2016$	$.0_5 864$	.99998	.99999

** The reliability shown is to be multiplied by .999916 (for 7 day) and .999964 (for 3 day) to include the effect of interconnections.

SUBSYSTEM: Data Management Subsystem RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY	
		7 Day	3 Day	7 Day	3 Day	7 Day	3 Day
Branch Box							
95 ICs	.03 HR	168 HR	72 HR	$.0_3467$	$.0_32952$	.99952	.99979
	.02 HR	168 HR	72 HR	$.0_33187$	$.0_31368$	.99968	.99986
Interconnecting 70,000	.0005 HR	168 HR	72 HR	.00588	.00252	.994137253-7 Day	.997483172-3 Day

The interconnection reliability is shared by 70 "IC" Boxes ∴ The interconnection reliability for each "IC" Box is the 70th root of the total interconnection reliability. — .999916 per "IC" Box - 7 Day; .999964 per "IC" Box - 3 Day

** The reliability shown is to be multiplied by .999916 (for 7 day) and .999964 (for 3 day) to include the effect of interconnections.

B2.6 Guidance and Navigation

Guidance and Navigation Analysis Assumptions

1) IMUs operate continuously throughout the mission

2) Horizon sensor reliability has been included although it could be omitted for all missions except Level I autonomy

3) Star tracker only operates for 30 minutes prior to each engine burn

SUBSYSTEM: Guidance & Navigation

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME	RELIABILITY
Provide Position, Velocity and Attitude Information		7 Day Mission	3 Day Mission		
IMU****: (All Avionics Configurations) Gyro Module - 6545 Hrs. MTBF		168 HR	72 HR	7 Day - .025668 - 3 Day - .011000 -	.97465 .98906
Accelerometer Module	65,450 HR MTBF	168 HR	72 HR	7 Day - $.0_2 256684$ - 3 Day - $.0_2 11000$ -	.99743 .99890
Provide Periodic Attitude Update		8 Engine Burns		8 Burns	8 Burns
Fixed Star Tracker (no gimbals) (All avionics configurations)	63,000 HR MTBF**	4 HR*		$.0_4 63191$	.99994
Provide Periodic Position Update					
Horizon Sensor (Optional on all avionics configurations)	17,700 HRS MTBF**	4 HR*		$.0_3 22598$	.99977

SUBSYSTEM: Guidance & Navigation

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Provide Long Range Rendezvous Capability Fixed Rendezvous (no gimbals) SLR Radar	1000 HRS MTBF**	1½ HR for docking (100 miles to rendezvous)	$.0_2150$	.99850
Docking Aide Fixed Video Subsystem (no gimbals)	10,000 HR MTBF (see attached sheet for failure rate data)	½ HR for docking	$.0_45000$	.99995

VIDEO SUBSYSTEM FAILURE RATES (FAILURES/10^6 HOURS)

INTENSIFIER TUBE	-	25.00	
VIDICON TUBE	-	25.00	
REGULATORS	-	3.15	
SYNCHRONIZER	-	.40	
DC/DC CONVERTER	-	.50	
CAMERA LENS	-	6.00	
ZOOM DRIVE	-	.6	
IRIS DRIVE	-	.6	
FOCUS COUPLING	-	.5	
LIMIT SWITCHES	-	2.0	
HIGH VOLTAGE SUPPLY	-	8.0	(FILTERS, REGULATORS, CHOPPERS, RECTIFIERS)
PRE-AMP	-	.150	
VIDEO AMP	-	.150	
DETECTOR CIRCUITS	-	.300	
TRANSFORMERS	-	.60	
APERTURE, CORE CIRCUITS	-	.30	
RESISTORS	-	3.00	

TOTAL $76.25/10^6$ HR $\approx$ 13,000 HR MTBF - USE 10,000 HR MTBF TO REMAIN CONSERVATIVE

NOTE: RCS VIDEO CAMERA SYSTEM FOR APOLLO USED FOR ESTIMATING PURPOSES.

SUBSYSTEM: Guidance & Navigation

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY

* Item operates maximum of 30 minutes prior to each engine burn only.

** Vendor data.

*** Vendor data - actual vendor data indicates 3000 HR and 5000 HR MTBF RESPECTIVELY. Existing Systems (AN/APQ-148, MOD #1 and #2) ARE NOT THAT GOOD, e.g., 500 and 750 HRS MTBF. THEREFORE, MORE CONSERVATIVE NUMBERS HAVE BEEN USED.

**** MTBF Data based on 2000 HR MTBF "State of the Art" for IMU Systems. For example,

Honeywell H-478 Strapdown IMU - 1957 HR MTBF
Honeywell H-488 Strapdown IMU - 1800 HR MTBF
NAR-MICRON - 2000 HR MTBF (Design Goal)
KEARFOTT - Data Not Available
Litton LN-30 - 3000 HR MTBF
Hamilton Standard - Gyro MTBF - 7000 Hr, Accelerometer MTBF - 70,000 Hr.

That data has been extrapolated for a single Gyro Module and a single Accelerometer Module (Accelerometer Module failure rate is approximately one-tenth of the Gyro Module failure rate) To estimate the reliability of a skewed redundant system.

RELIABILITY CALCULATION FOR SKEWED REDUNDANT IMUs

GIVEN: SIX GYRO MODULES
SIX ACCELEROMETER MODULES

REQUIRED FUNCTION: FOUR GYRO MODULES
FOUR ACCELEROMETER MODULES

$$\therefore R_{\text{REDUNDANCY}} = \left[R^6_{\text{ONE GYRO MODULE}} + \left(6\ R^5_{\text{ONE GYRO MODULE}} \times U_{\text{ONE GYRO MODULE}}\right) + \left(15\ R^4_{\text{ONE GYRO MODULE}} \times U^2_{\text{ONE GYRO MODULE}}\right)\right] \times \left[R^6_{\text{ONE ACCELEROMETER MODULE}} + \left(6\ R^5_{\text{ONE ACC. MODULE}} \times U_{\text{ONE ACC. MODULE}}\right) + \left(15\ R^4_{\text{ONE ACC. MODULE}} \times U^2_{\text{ONE ACC. MODULE}}\right)\right]$$

Where: R=Reliability
U=Unreliability = 1 - Reliability

$R_{\text{ONE GYRO MODULE}}$ = .97465 (SEVEN DAY MISSION)
$R_{\text{ONE ACC. MODULE}}$ = .99743 (SEVEN DAY MISSION)

$$\therefore \text{IMU RELIABILITY (7DAY MISSION)} = (.8572196 + .1337742 + .0085984) \times (.9846787 + .0152228 + .0000980) = .99969$$

SIMILAR CALCULATIONS GIVE 3 DAY RELIABILITY

B2.7 Docking

Docking Subsystem Reliability Analysis Assumptions:

1. The Apollo Probe system is used for reliability estimating purposes.

2. The docking operation is assumed to take 2 hours.

3. Probe spin up is assumed to take 2 hours and despine thirty minutes.

4. The worst case docking operation consists of deploying one spacecraft, docking to a second spacecraft and then deploying the second spacecraft. Two deployments and one retrieval. (Nudge Mode)

5. Deployment is assumed to take 15 minutes.

SUBSYSTEM: DOCKING (USE APOLLO PROBE FOR RELIABILITY ESTIMATING) RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Deploy Probe				
Pneumatic Supply Tank	.07 — Hr	40 hours	$.0_5 28$	
Solenoid Valve	12.4 — Cycles	4 cycles	$.0_4 496$	
Regulator	2.03 — Hr	30 minutes	$.0_5 1015$	
Check Valve	2.5 — Hr	30 minutes	$.0_5 1015$	
(3) Relief Valve	.2 — Hr	40 hours	$.0_5 8000$	
Probe Mechanism (Pneumatic Actuator)	5.1 — Hr	30 minutes	$.0_5 255$	
(4) Relays	.25 — Hr	30 minutes	$.0_6 50$	
			$.0_4 6548$	.99993
Spin Up Probe*				
DC Torque Motor	2.5 — Hr	2 hours		
(4) Relays	.25 — Hr	2 hours		
Rheostat Control	.13 — Hr	2 hours		
	$2.88/10^6$ hours	2 hours + 32 Hours Nonoperate at .1 X the operating failure rate.	$.0_5 576$ $.0_5 926$ $.0_4 14976$	.99998

* Representative components

SUBSYSTEM: DOCKING

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Provide Soft Dock				
(3) Attenuators Probe Latch	50 —— Cycles 50 —— Cycles	Assume maximum of 10 per dock.		
	$100/10^6$ cycles	10	$.0_21$	.99900

SUBSYSTEM: DOCKING

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Despin Probe				
	Use same hardware and failure rates as for "spin up probe" but add environmental factor due to increased load, say 5 (per MIL-HANDBOOK-217A), therefore;			
	$5X2.88/10^6$ Hr	30 minutes	$.0_5 7200$	.99999

SUBSYSTEM: Docking

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Spacecraft * Deployment				
Release (or Capture) Mechanism				
Solenoid Valve	12.4 —— Cycles	2 cycles	$.0_4248$	
Regulator	2.03 —— HR	15 minutes	NIL	
Pneumatic Actuator	5.1 —— HR	15 minutes	$.0_51275$	
Supply Tank	.07 —— HR	40 HRS	$.0_52800$	
			$.0_428875$	.99997
Spacecraft * Deployment				
Deploy Probe	Same hardware as used for retrieving spacecraft			.99993

* Representative hardware - similar to the Apollo Probe

B2.8 Engines

Engine Reliability Analysis Assumptions:

1) The ALRC OME schematics are used for reliability estimating for both the OME and Class I engine

2) No. of engine starts for OME and Class I engine:

   1 stage vehicle - 8 starts - round trip or deploy/retrieve

   and stage and a half - 6 starts - deploy only

3) Engine burn time: OME - 2500 seconds
   Class I and uprated OME - 1600 seconds

4) Failure rates include K factor for environment as the data is specifically for Rocket engine components (ref: Standord Research Institute Report on "Reliability Estimation for Chemical Propulsion Systems".

OME and Class I

SUBSYSTEM: Engine

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY
		7 Day	3 Day			
Engine (Re) Start Control-Mono-propellant Starter						
He Tank	.07 — Hr	168 Hr	72 Hr			
Press. Reg.	1.12 — Hr	"	"			
N_2H_4 Tank	.15 — Hr	"	"			
Metal Bellows	1.4 — Hr	"	"			
				$.0_{3}460320$	$.0_{3}197280$	7 Day
Starter Valve	150 — Cycles	8 & 6 cycles	8 & 6 cycles			.99147
Gas Gen.	200 — Cycles	8 & 6 cycles	8 & 6 cycles			.99346
Turbine	10 — Hr	4 & 3 sec	4 & 3 sec	Cycles		
Gear Drive	1 — Hr	4 & 3 sec	4 & 3 sec	$.0_{2}760$		
Pump, Ox.	13.5 — Hr	4 & 3 sec	4 & 3 sec	$.0_{2}570$		
Pump, Fuel	13.5 — Hr	4 & 3 sec	4 & 3 sec			
Valve, Fuel	150 — Cycles	8 & 6 cycles	8 & 6 cycles	Hours		
Valve, Ox.	150 — Cycles	8 & 6 cycles	8 & 6 cycles	$.0_{7}558$		
Injector	100 — sec	4 & 3 sec	4 & 3 sec	$.0_{7}446$		
Thrust Chamber	.01 — sec	4 & 3 sec	4 & 3 sec			
Ox. Press. Sw.	1.10 — Hr	4 & 3 sec	4 & 3 sec	Seconds		
Fuel Press. Sw.	1.10 — Hr	4 & 3 sec	4 & 3 sec	$.0_{3}500050$		
Gas Gen.				$.0_{3}400040$		
Fuel Valve	150 — Cycles	8 & 6 cycles	8 & 3 cycles			
Ox. Valve	150 — Cycles	8 & 6 cycles	8 & 3 cycles			
						3 Day
						.99173
						.99372

OME AND CLASS I

SUBSYSTEM: ENGINE

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Engine Combustion Control		2500 sec 1600 sec	2500 sec 1600 sec	
Gas Gen	.1 sec		$.0_3250$ $.0_3160$	
Turbine	10 Hr		$.0_5694$ $.0_5444$	
Gear Drive	1 Hr		$.0_6694$ $.0_6444$	
Pump, Ox.	13.5 Hr		$.0_5937$ $.0_56$	
Pump, Fuel	13.5 Hr		$.0_5937$ $.0_56$	
Injector	100 Hr		$.0_4694$ $.0_4444$	
Thrust Chamber	.01 sec		$.0_4250$ $.0_4160$	
Ox. Press. Sw.	1.10 Hr		$.0_6764$ $.0_6489$	
Fuel Press.Sw.	1.10 Hr		$.0_6764$ $.0_6489$	
Piping	.20 Hr		$.0_6139$ $.0_7888$	
			$.0_3372$ $.0_3238$	
				2500 sec=.99963 1600 sec=.99976

OME AND CLASS I

SUBSYSTEM: ENGINE

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME		RELIABILITY
Engine Shutdown Control		7 Day and 3 Day			
Fuel Valve	150 Cycles	8 & 6 cycles	$.0_2 120$	$.0_3 700$	
Ox Valve	150 Cycles	8 & 6 cycles	$.0_2 120$	$.0_3 900$	
Ox Press. Sw.	1.10 Hr	4 & 3 sec	NIL	NIL	
Fuel Press. Sw	1.10 Hr	4 & 3 sec	NIL	NIL	
Gas Gen.					
Fuel Valve	150 Cycles	8 & 6 cycles	$.0_2 120$	$.0_3 900$	
Ox Valve	150 Cycles	8 & 6 cycles	$.0_2 120$	$.0_3 900$	
Gas Gen.	200 Cycles	8 & 6 cycles	$.0_2 160$	$.0_2 120$	
Turbine	10 Hr	4 & 3 sec	$.0_7 111$	$.0_7 1$	
Gear Drive	1 Hr	4 & 3 sec	$.0_7 111$	$.0_7 1$	
Pump, Ox	13.5 Hr	4 & 3 sec	$.0_7 15$	$.0_7 1$	
Pump, Fuel	13.5 Hr	4 & 3 sec	$.0_7 15$	$.0_7 1$	
Injector	100 sec	4 & 3 sec	$.0_4 4$	$.0_4 3$	
Thrust Chamber	.01 sec	4 & 3 sec	NIL	NIL	
			$.0_2 644$	$.0_2 485$	.99358 (8 Cycle) .99516 (6 Cycle)

B2.9 Main Engine Support

(Propellant and Pressurization)

Assumptions in PR Main Engine Support

Subsystem Reliability Analysis

1. Number of Main Engine Firings - 8 for all configurations and missions (maximum)

2. Duration (total) of Main Engine Firings - 2500 sec. max for all configurations and missions.

3. Where a particular failure mode for a component does not reduce the probability of success to that subsystem, the failure rate is adjusted down appropriately.

4. The time division in PR-1(5) is:

   Drop Tanks - 1 day in Shuttle + 8 hours active

   Stage - 1 day in Shuttle + 2 days or 4 days active

5. The only part the dump system plays in the subsystem reliability is "leakage" since that system does not function except in an abort situation.

MAIN ENGINE SUPPORT
SUBSYSTEM: PR-1(2)

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY	
		7 Day	3 Day	7 Day	3 Day	7 Day	3 Day
He Gas Storage							
Tank	.07 Hr.	168 Hr	72 Hr				
Fill Valve	.65 Hr	"	"				
Cap/Lines	.40 Hr	"	"				
				.0001881	.0000806	.99981	.99991
Ox Tank Pressure Control							
Solenoid Valve	12.4 Cycles	10 cycles		$.0_{3}1240$			
Regulator	2.03 Hr	2500 sec		$.0_{5}1409$			
Regulator	2.03 Hr	2500 sec		$.0_{5}1409$			
Check Valve	2.5 Hr	2500 sec		$.0_{5}1736$			
Solenoic Valve	12.4 Cycles	10 cycles		$.0_{3}1240$			
Rel. Valve	.57 Hr	2500 sec		$.0_{6}395$			
Burst Disc	.20 Hr	2500 sec		$.0_{6}138$			
Cap/Disc	.20 Hr	2500 sec		$.0_{6}138$			
				$.0_{3}253225$		.99975	
Fuel Tank Pressure Control	SAME AS ABOVE						

MAIN ENGINE SUPPORT
SUBSYSTEM: PR-1(2)

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Propellant Vapor Back Flow Control Check Valve Solenoid Valve Solenoid Valve Solenoid Valve Solenoid Valve	 2.5 —— Hr 6.2 —— Cycles 6.2 —— Cycles .65 —— Hr .65 —— Hr			All have to fail (3 failures) to have back flow: $R=(1-Q^3)\approx(1-)$ R=.99999
Fuel Feed Solenoid Valve Cap/Lines	 6.2 —— Cycles .40 —— Hr	7 Day: 10 cycles, 168 Hr 3 Day: 10 Cycles, 72 Hr	7 Day: $.0_31292$ $.0_4620$ 3 Day: $.0_4288$	7 Day: .99987 3 Day: .99990
Ox Feed	SAME AS ABOVE			
Fuel Acquisition Screen/Trap	1.4 —— Hr	168 Hr / 72 Hr	.000235 / .0001008	.99976 / .99989
Ox Acquisition	SAME AS ABOVE			.99976 / .99989

MAIN ENGINE SUPPORT
SUBSYSTEM: PR-1(2)

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY	
		7 Day	3 Day	7 Day	3 Day	7 Day	3 Day
Propellant Utilization							
Fuel Probe	*3.82 Hr	2500 sec			$.0_5 2652$		
	.38 Hr	602800 Sec	257200	.0000636	.0000271		
Ox Probe	**3.57 Hr	2500 sec			$.0_5 2478$		
	.35 Hr	602800 Sec	257200	.0000586	.0000250		
Adjustable Valve	+4.8 Hr	360 sec			.00000048		
	.48 Hr	604440 Sec	258840	.0000805	.0000345		
Control Unit	***.5 Hr	2500 sec			$.0_6 208$		
	.2 Hr	602800 Sec	257200	.0000334	.0000142		
				.000242	.0001066	.99975	.99989

* = Capacitor + Transformer + wiring + temperature sensor + connector + wiring
**= Capacitor + temperature sensor + compensating capacitor + insulator + wiring
***= 10 integrated circuits

\+ = Valve + gears + servo amplifier + motor

Note: First Number in Failiure Rate Column for a component indicates operating time failure rate and second number indicates non-operating time failure rate. In the operating time column the same is true, ie., First number is operating time and second number is non-operating time.

MAIN ENGINE SUPPORT
SUBSYSTEM: PR-1(2)

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Fuel Dump (This calculates probability of being able to dump)				
Solenoid Valve	$6.2/10^6$ cycle	1 cycle	.0000062	
Solenoid Valve	$6.2/10^6$ cycle	1 cycle	.0000062	
Solenoid Valve	$6.2/10^6$ cycle	1 cycle	.0000062	
Disconnect	.20	1 hour	.0000004	
Lines/Fittings	.20	1 hour		
			$.0_4190$	.99999
Oxidizer Dump (This calculates probability of being able to dump)				
Solenoid Valve	$6.2/10^6$ cycle	1 cycle	.0000062	
Solenoid Valve	$6.2/10^6$ cycle	1 cycle	.0000062	
Solenoid Valve	$6.2/10^6$ cycle	1 cycle	.0000062	
Disconnect	.20	1 hour	.0000004	
Lines/Fittings	.20	1 hour		
			$.0_4190$	.99999
Fuel Dump (As part of fuel feed - "leakage" only)		168 HR 72 HR		
Solenoid Valve	11.0 HR*		$.0_21848$ $.0_3792$	
Solenoid Valve	11.0 HR*			
Lines/Fittings	2.0 HR		$.0_4336$ $.0_4144$	
				.99996 .99998
Ox Dump (As part of Ox feed-"leakage" only)	11.0 HR*	168 HR 72 HR	$.0_21848$ $.0_3792$	
	11.0 HR*			
	2.0 HR		$.0_4336$ $.0_4144$	
				.99996 .99998

* Valves are series redundant against leak ∴ $R=1-Q^2$, where Q = Probability of leak valves.

SUBSYSTEM: MAIN ENGINE SUPPORT-DROP TANK PORTION PR-1(5)

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
He Gas Storage				
Tank	.07 Hr	32 hours		
Fill Valve	.65 Hr	"		
Cap	.20 Hr	"		
Lines	.20 Hr	"	.0000358	.99996
Ox Tank Pressure Control				
Solenoid Valve	$12.4/10^6$ Cycles	4 cycles	.0000496	
Regulator	2.03 Hr	1200 sec		
Regulator	2.03 Hr	1200 sec	.0000022	
Check Valve	2.5 Hr	1200 sec		
Solenoid Valve	12.4 Cycles	4 cycles	.0000496	
Relief Valve	.57 Hr	1200 sec		
Burst Disc	.20 Hr	1200 sec	.00000032	
Cap/Disc	.20 Hr	1200 sec		.99989
Fuel Tank Pressure Control	SAME AS ABOVE			.99989

SUBSYSTEM: MAIN ENGINE SUPPORT - DROP TANK PORTION PR-1(5)

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS		OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Back Flow Control					
Check Valve	2.5	Hr	32 hours		All have to fail
Solenoid Valve	6.2	Cycles	4 cycles	.000099	to have back flow
Solenoid Valve	6.2	Cycles	4 cycles		.. $R=1-Q^3=(1-)$
Solenoid Valve	.65	Hr	32 hours	.0001216	
Solenoid Valve	.65	Hr	32 hours		
Fuel Feed					
Solenoid Valve	6.2	Cycles	4 cycles	.0000248	
Cap/Lines	.40	Hr	32 hours	.0000128	
					.99998
Oxidizer Feed					
Solenoid Valve	6.2	Cycles	4 cycles	.0000248	
Cap/Lines	.40	Hr	32 hours	.0000128	
					.99998
Fuel Acquisition					
Screen Trap	1.4	Hr	32 hours	.0000448	.99995
Oxidizer Acquisition					
Screen Trap	1.4	Hr	32 hours	.0000448	
					.99995

MAIN ENGINE SUPPORT - DROP TANK

SUBSYSTEM: PORTION PR-1(5)

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Propellant Utilization				
Fuel Probe	3.82 Hr	Op - 1200 sec	.00000127	
	.38 Hr	Non-114000 sec	.00001203	
Ox Probe	3.57 Hr	Op - 1200 sec	.00000119	
	.35 Hr	Non-114000 sec	.00001108	
Adjustable Valve	4.8 Hr	Op - .1 hour	.00000048	
	.48 Hr	Non-114000 sec	.0000152	
Control Unit	.3 Hr	Op - 1200 sec	.0000001	
	.2 Hr	Non-114000 sec	.00000633	
			.0000476	.99995
Fuel Oxidizer Drop Tank Disconnects	1.46 Hr	8 hours	.0000116	.99998
Ox Disc				
Fuel Disc				

SUBSYSTEM: Main Engine Support - Stage PR-1(5)

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY	
He Gas Storage		7 Day	3 Day	7 Day	3 Day	7 Day	3 Day
Tank	.07 — HR	168 HR	72 HR				
Fill Valve	.05 — HR	168 HR	72 HR				
Cap	.20 — HR	168 HR	72 HR				
Lines	.20 — HR	168 HR	72 HR				
				.000188	.0000806	.99981	.99991
Ox Tank Pressure Control				7 & 3 Day		7 & 3 Day	
Sol Valve	12.4 — Cycles	4 Cycles		.00000448			
Regulator	2.03 — HR	800 Sec		.00000045			
Regulator	2.03 — HR	800 Sec		.00000045			
CK Valve	2.5 — HR	800 Sec		.00000056			
Sol Valve	12.4 — Cycles	4 Cycles		.00000448			
Rel. Valve	.57 — HR	800 Sec		.00000012			
Burst Disc	.20 — HR	800 Sec		.00000004			
Cap/Disc	.20 — HR	800 Sec		.00000004			
				.0000106		.99998	
Fuel Tank Pressure Control		SAME AS ABOVE				.99998	

Main Engine Support -
SUBSYSTEM: Stage PR-1(5)

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Back Flow Control CK Valve Sol Valve Sol Valve Sol Valve Sol Valve	 2.5 —— HR 6.2 —— Cycle 6.2 —— Cycle .65 —— HR .65 —— HR			All (3) components have to fail to have back flow ∴ $R = 1 - Q^3$ = (1-) = .99999
Fuel Feed Sol Valve Cap/Lines	 6.2 —— Cycle .40 —— HR	7 Day / 3 Day 4 Cycle 108 HR / 36 HR	7 Day / 3 Day .0000248 .0000432 / .0000144	7 Day / 3 Day .99993 / .99996
Ox Feed	SAME AS ABOVE			.99993 / .99996
Fuel Acquisition Screen-Trap	1.4 —— HR	108 HR / 36 HR	.000151 / .0000504	.99984 / .99994
Ox Acquisition	SAME AS ABOVE			.99984 / .99994

SUBSYSTEM: Main Engine Support - Stage PR-1(5)

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY	
Prop. Utilization		7 Day	3 Day	7 Day	3 Day	7 Day	3 Day
Fuel Probe	3.82 HR	800 Sec	800 Sec	.00000084			
	.38 HR	604000	258400	.0000637	.0000272		
Oxidizer Probe	3.57 HR	800 Sec	800 Sec	.00000079			
	.35 HR	604000	258400	.0000352	.0000251		
Adjustable Valve	4.8 HR	.1 HR	.1 HR	.00000048			
	.48 HR	604000	258400	.0000805	.000034		
Control Unit	.3 HR	800 Sec	800 Sec	.00000006			
	.2 HR	604000	258400	.0000335	.0000143		
				.000215	.000102	.99978	.99989

B2.10 Attitude Control System

VOLUME 5.0

ATTITUDE CONTROL SYSTEM RELIABILITY ANALYSIS ASSUMPTIONS

1) THRUSTER VALVES OPERATE ABOUT 6500 CYCLES FOR EACH MISSION (WORST CASE)

2) MISSION DURATION FOR THIS SYSTEM IS 7 DAY and 3 DAYS RESPECTIVELY

3) DUTY CYCLE OF HEATERS IS 25% TO 30% OF THE MISSION TIME

ACPS-2(8)

SUBSYSTEM: Attitude Control System

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS		FAILURE RATE X OPERATING TIME		RELIABILITY	
		7 Day Mission	3 Day Mission	7 Day	3 Day	7 Day	3 Day
Gas Storage							
Tank	.07 HR	168 HR	72 HR				
Lines	.20 HR	EACH	EACH				
Valve	.65 HR	COMPONENT	COMPONENT				
Cap	.20 HR						
Transducer	.20 HR						
	$1.32/10^6$ HR	168	72	$.0_3 22176$	$.0_4 9504$	.99979	.99990
Gas Flow Control							
Solenoid Valve	11.0 HR	2 HR	1 HR	$.0_4 22$	$.0_4 11$		
Filter	.3 HR	168 HR	72 HR				
Regulator	2.03 HR	168 HR	72 HR	$.0_3 7325$	$.0_3 31392$		
Regulator	2.03 HR	168 HR	72 HR				
				$.0_3 7545$	$.0_3 32492$	.99925	.99968
Fuel Storage							
Tank	.15 HR	168 HR	72 HR				
Screen	1.4 HR	EACH	EACH				
Relief Valve	.57 HR	COMPONENT	COMPONENT				
Fill Valve	.65 HR						
Lines	.20 HR						
Cap	.20 HR						
	$3.17/10^6$ HR	168	72	$.0_3 53256$	$.0_3 22824$	.99947	.99977
Fuel Flow Control							
Filter	.3 HR	168 HR	72 HR	$.0_4 504$	$.0_4 216$		
Solenoid Valve	11.0 HR	2 HR	1 HR	$.0_4 22$	$.0_5 9428$		
				$.0_4 724$	$.0_4 31028$	.99993	.99996

ACPS-2(8)

SUBSYSTEM: Attitude Control System

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Thrusters				
Solenoid Valve	.27 CYCLES	6500 CYCLES		
Solenoid Valve	.27 CYCLES	6500 CYCLES		
Nozzle	.1 CYCLES	6500 CYCLES		
	$.64/10^6$ CYCLES	6500 CYCLES	$.0_2416$	.99584
Back Flow Control				
Quad Redundant Check Valves	2.5 HR per valve	168 HR / 72 HR	.0042/valve X 2 valves in series = .0084 ∴ R = .99163 for one series string	Reliability is 1 minus the unreliability squared for each parallel string of the two series valves = .99993 for 7 days
Thermal Control		7 Day Mission / 3 Day Mission		
9 Strip Heaters	.010 HR	50 HRS* / 30 HR*		
9 Thermo Switch	.014 HR	50 HRS / 30 HR	7 Day / 3 Day	7 Day / 3 Day
	$.024/10^6$ HR	50 HR / 30 HR	$.0_512$ / $.0_672$	.99999 / .99999

*Approximately 25 - 30% duty cycle

B2.11 Orbiter Interface

SUBSYSTEM: ORBITER INTERFACE

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Fuel Dump * Disconnect	50 Cycle	2 Cycles	$.0_3 1$	.99990
Oxidizer * Dump Disconnect	50 Cycle	2 Cycles	$.0_3 1$	.99990
Electrical * Disconnect	50 Cycle	2 Cycles	$.0_3 1$	.99990
Electrical Function (7 pins)	.4/Pin HR	24 Hours	$.0_4 672$	.99993

* Assume reconnect failure rate is the same as disconnect failure rate (in the absence of better data to the contrary)

SUBSYSTEM: ORBITER INTERFACE

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Cradle * Actuator	6.9 HR	1 HR		
Actuation * Mechanism				
Gears	2.175 HR	1 HR		
Motor	2.5 HR	1 HR		
Controls	.25 HR	1 HR		
	$11.825/10^6$ HR	1 HR	$.0_4 11825$	.99998

*Representative Hardware

B2.12 Spacecraft Separation System

SUBSYSTEM: Spacecraft Separation System

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Squib Firing Circuit Assy *				
1 capacitor 10 transistors 10 resistors 5 diodes 1 switch 1 relay 1 transformer	.27 HR .04 HR .05 HR .02 HR .25 HR .25 HR .3 HR $2.07/10^6$ HR	32 Hrs (non-operating at 2/3 the operating failure rate) plus 5 minutes operating - each component	$(2/3 \times 2.07/10^6 \times 32) + 2.07/10^6 \times .0833$ Hr = $.0_4 4416 + .0_6 1724 = .0_4 44332$	.99995
Squib	300 cycles	1 cycle	.0003	.99970
Detonating Block	30 cycles	1 cycle	.00003	.99997
Electrical Detonating Cord	30 cycles	1 cycle	.00003	.99997

* Representative hardware

SUBSYSTEM: Spacecraft Separation

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Spring Loaded * Actuator (to separate spacecraft/Tug)	.110 HR	32 hour non-operate + one shot operation (less than 1 second)	$.0_5 2346$ + NIL = $.0_5 2346$	.99999

* Representative hardware

B2.13 <u>Drop Tank Separation Mechanism</u>

Drop Tank
Separation
SUBSYSTEM: Mechanism

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Structural * Separation	(2 places, each tank)			
Squib Firing Circuit Assy	2.07/10^6 HR (identical to spacecraft separation squib firing circuit assy)	32 HRS non-operating at 2/3 the operating failure rate) plus 5 minutes operating	$.0_4 44332$	.99995
Squib	300 — cycle	1 cycle	.0003	.99970
Detonating Block	30 — cycle	1 cycle	.00003	.99997
Electrical Detonating Cord	30 — cycle	1 cycle	.00003	.99997
Fluid Connector* Separation	(1, each tank)			
ordnance portion same as above except for detonating cord				
Substitute:				
(2) Pin Puller	300 — cycle	1 cycle	.0003	.99970

* Representative hardware

SUBSYSTEM: Drop Tank Separation Mechanism

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Spring Loaded * Clamp	.110 HR	32 HR non-operate + one shot operation (less than 1 second)	$.0_5 2346$ + NIL = $.0_5 2346$	.99999
<u>Positive * Drop Tank Thrust Device</u>				
(2) Solenoid Valve (to direct tank pressure source after Drop Tank Separation)	12.4 cycles	1 cycle	$.0_4 124$	.99998

* Representative hardware

B2.14 Kickstage

KICK STAGE RELIABILITY

ANALYSIS SUMMARY

Either KS-10 or KS-1.5

Subsystem	Reliability
RCS	.99945
SRM	.99949
Power	.99999
Guidance and Navigation	.99764
Data Management	.99995
Kick Stage Total	.99652
Kick Stage Separation (Same as spacecraft separation)	.99995

KICK STAGE RELIABILITY ANALYSIS ASSUMPTIONS

1. ENGINE BURN TIME 190 SECONDS
2. KICK STAGE OPERATIONAL LIFE - TWENTY MINUTES EXCEPT AS NOTED:

   GYROS - 14 HOURS (SPUN UP AT TUG DEPLOYMENT)
3. KICK DEPARTS TUG 32 HOURS AFTER SHUTTLE LIFT OFF
4. PRIOR TO DEPARTING THE TUG, THE TUG DATA MANAGEMENT CONTROLS THE KICK STAGE AND KICK STAGE DATA MANAGEMENT IS IN SLAVE MODE.

SUBSYSTEM: KICKSTAGE RCS

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Pitch/Yaw/Roll Control Gas Storage				
N_2 Storage	.07 HR	24 hours in Shuttle plus 10 hrs operation time to deployment equals 34 hours for each component		
Transducer	.20 HR			
Hand Valve	.65 HR			
Cap	.20 HR			
Relief Valve	.57 HR			
Burst Disc	.20 HR			
Lines	.20 HR			
N_2 Sphere	.07 HR			
Transducer	.20 HR			
Hand Valve	.65 HR			
Cap	.20 HR			
Lines	.20 HR			
	$3.41/10^6$ HR	34	$.0_3 11594$	.99988
Flow Control				
Solenoid Valve	.27 cycle	2 cycles/min, 20 minutes - 40	$.0_4 108$	
Regulator	2.03 HR	20 minutes	$.0_6 676$	
			$.0_4 11476$	.99998

SUBSYSTEM: KICK STAGE RCS

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Propellant Storage				
N_2H_4 Storage	.15 Hr	Operating time same as above for each component		
Diaphragm (Metal)	.8 Hr			
Fill Cap	.20 Hr			
	$1.15/10^6$ Hr	34	$.0_4391$	.99996
Propellant Flow Control				
Solenoid Valve	.27 Cycle	One cycle - open once	$.0_627000$	
Filter	.3 Hr	20 minutes	$.0_610000$	
			$.0_637000$	.99999
Pitch, Yaw or Roll Nozzle Control				
Solenoid Valve	$.27/10^6$ Cycles	2 cycles/minute for a total of twenty minutes operating time for payload insertion		
Solenoid Valve	$.27/10^6$ Cycles			
Thruster	$.1/10^6$ Cycles			
	$.64/10^6$ Cycles	40 cycles	$.0_4256$	.99997

SUBSYSTEM: SRM - Kickstage

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
SRM				
Grain	300 —— Units	1 Unit	$.0_{3}300$	
Case	20 —— Units	1 Unit	$.0_{4}200$	
Nozzle	.1 —— Sec	190 Sec	$.0_{4}190$	
Insulation	.3 —— Sec	190 Sec	$.0_{4}570$	
Liner	100 —— Units	1 Unit	$.0_{3}100$	
			$.0_{3}4960$	.99950
SRM Ignition				
Ignitor	100 —— Units	1 Unit	$.0_{3}100$	
Initiator	50 —— Units	1 Unit	$.0_{4}500$	
			$.0_{3}15$	.99985
Safe/Arm/Fire Device *				
Capacitor	.27 —— Hrs	32 Hours - Non-operating (2/3 operating failure rate) plus 5 minutes operating - each component	$2/3 \times 11.27/10^6 \times 32$ HR. $+ 11.27/10^6 \times .0833$ HR $= .0_{3}240 + .0_{6}9391$	
10 Transistors	.04 —— Hrs			
10 Resistors	.05 —— Hr			
5 Diodes	.02 —— Hr			
1 Air Gaptube	10.0 —— Hr			
	$11.27/10^6$ Hr		$.0_{3}241365$	.99976

* Representative Components

SUBSYSTEM: Power Subsystem - Kickstage RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Power Supply				
Battery (one shot)	1.4 —— HR	20 Minutes		
Diode	.02 —— HR	20 Minutes		
	1.42/10^6 HR	20 Minutes	$.0_6 47333$	.99999
Power Distribution*				
Remote Switch	.5 —— HR	20 Minutes	$.0_6 1666$	
Bus	.02 —— HR	20 Minutes	NIL	
(15) S/S Circuit Breaker**	.733 —— HR	20 Minutes + 32 Hrs Non-Operate	$.0_3 237003$	
(15) Remote Power Controller**	.733 —— HR	20 Minutes + 32 Hrs Non-Operate	$.0_3 237003$	
			$.0_3 474173$	.99953

*Same component failure rates as stage Power Distribution.
**Estimated No. of Components.

KICK STAGE
SUBSYSTEM: GUIDANCE & NAVIGATION

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
Provide attitude and velocity information				
(3) Gyro* Module	6545 Hr. MTBF	14 hours	$.0_2 21390$	.99786
(3) Velocity* Meter Module	65,450 Hr. MTBF	14 hours	$.0_3 21390$	.99978

*MTBF identical to Stage MTBF.

SUBSYSTEM: KICK STAGE, DATA MANAGEMENT

RELIABILITY ANALYSIS WORKSHEET

COMPONENT	FAILURE RATE/10^6 HR, CYCLES, UNITS	OPERATING TIME HR, CYCLES, UNITS	FAILURE RATE X OPERATING TIME	RELIABILITY
GP Processor				
100 IC's	.03 ——— Hr	32 hours	$.0_4960$	.99990
(4) Cabling & Connectors	.03 ——— Hr	32 hours	$.0_5384$	.99999
Memory				
160 IC's	.03 ——— Hr	32 hours	$.0_31536$	.99985
CDTC Processor				
150 IC's	.03 ——— Hr	32 hours	$.0_3144$	.99986
Branch Box				
(2) 50 IC's	.03 ——— Hr	32 hours	$.0_4960$	.99990

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APPENDIX C

MITAS INPUT FOR TUG THERMAL MODELS

APPENDIX C

TABLE OF CONTENTS

Table C-1 MITAS Input for Tug Thermal Model with MLI.

NOT RECALL

```
BCD 3THERMAL LPCS                                                  1   06/13/73.  NEW
BCD 9 CONFIG 2,NO MLI,NO RAD,LONG TOWARD SUN                       2   06/13/73.  NEW
END                                                                3   06/13/73.  NEW
BCD 3NODE DATA                                                     4   06/13/73.  NEW
GEN 1, 18, 1, 70., 1.81, 1., 1., 1.$                               5   06/13/73.  NEW
                     1,  7.00000E+01,  1.81000E+00
                     2,  7.00000E+01,  1.81000E+00
                     3,  7.00000E+01,  1.81000E+00
                     4,  7.00000E+01,  1.81000E+00
                     5,  7.00000E+01,  1.81000E+00
                     6,  7.00000E+01,  1.81000E+00
                     7,  7.00000E+01,  1.81000E+00
                     8,  7.00000E+01,  1.81000E+00
                     9,  7.00000E+01,  1.81000E+00
                    10,  7.00000E+01,  1.81000E+00
                    11,  7.00000E+01,  1.81000E+00
                    12,  7.00000E+01,  1.81000E+00
                    13,  7.00000E+01,  1.81000E+00
                    14,  7.00000E+01,  1.81000E+00
                    15,  7.00000E+01,  1.81000E+00
                    16,  7.00000E+01,  1.81000E+00
                    17,  7.00000E+01,  1.81000E+00
                    18,  7.00000E+01,  1.81000E+00
39, 70., 18.5$                                                     6   06/13/73.  NEW
GEN 40, 18, 1, 70., 1.112, 1., 1., 1.$                             7   06/13/73.  NEW
                    40,  7.00000E+01,  1.11200E+00
                    41,  7.00000E+01,  1.11200E+00
                    42,  7.00000E+01,  1.11200E+00
                    43,  7.00000E+01,  1.11200E+00
                    44,  7.00000E+01,  1.11200E+00
                    45,  7.00000E+01,  1.11200E+00
                    46,  7.00000E+01,  1.11200E+00
                    47,  7.00000E+01,  1.11200E+00
                    48,  7.00000E+01,  1.11200E+00
                    49,  7.00000E+01,  1.11200E+00
                    50,  7.00000E+01,  1.11200E+00
                    51,  7.00000E+01,  1.11200E+00
                    52,  7.00000E+01,  1.11200E+00
                    53,  7.00000E+01,  1.11200E+00
                    54,  7.00000E+01,  1.11200E+00
                    55,  7.00000E+01,  1.11200E+00
                    56,  7.00000E+01,  1.11200E+00
                    57,  7.00000E+01,  1.11200E+00
GEN 58, 18, 1, 70., 4.51, 1., 1., 1.$                              8   06/13/73.  NEW
                    58,  7.00000E+01,  4.51000E-01
                    59,  7.00000E+01,  4.51000E-01
                    60,  7.00000E+01,  4.51000E-01
                    61,  7.00000E+01,  4.51000E-01
                    62,  7.00000E+01,  4.51000E-01
                    63,  7.00000E+01,  4.51000E-01
                    64,  7.00000E+01,  4.51000E-01
                    65,  7.00000E+01,  4.51000E-01
                    66,  7.00000E+01,  4.51000E-01
                    67,  7.00000E+01,  4.51000E-01
                    68,  7.00000E+01,  4.51000E-01
                    69,  7.00000E+01,  4.51000E-01
                    70,  7.00000E+01,  4.51000E-01
```

```
                71,   7.00000E+01,   4.51000E-01
                72,   7.00000E+01,   4.51000E-01
                73,   7.00000E+01,   4.51000E-01
                74,   7.00000E+01,   4.51000E-01
                75,   7.00000E+01,   4.51000E-01
78, 70., 12.92$
79, 70., 70.8$
80, 70., 600.$
81, 70., 1.$
82, 70., 1.$
38, 70., 8.343
77, 70., 16.68$
37, 70., -1.$
76, 70., -1.$
137, 70., -1.$
176, 70., -1.$
-85, -460., 1.$
END
```

```
  9    06/13/73.  NEW
 10    06/13/73.  NEW
 11    06/13/73.  NEW
 12    06/13/73.  NEW
 13    06/13/73.  NEW
 14    06/13/73.  NEW
 15    06/13/73.  NEW
 16    06/13/73.  NEW
 17    06/13/73.  NEW
 18    06/13/73.  NEW
 19    06/13/73.  NEW
 20    06/13/73.  NEW
 21    06/13/73.  NEW
```

ACTUAL NODE NUMBERS

REL. NODE NO.	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1 - 20	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	39	40
21 - 40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
41 - 60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	78	79	80	81	82
61 - 67	38	77	37	76	137	176	65													

```
BCD 3CONDUCTOR DATA
1, 77,82, 78, 82, 42.1$
3, 78,81, 38,81, 42.1$
5, 39, 81, 45.6$
214, 76, 176, 37, 137, 7.-4*72./.0333$
GEN -24, 18, 1, 1, 1, 85, 0, .1713E-8, 1., 9.970, 1.$
                  -24,      1,    85,   1.70786E-06
                  -25,      2,    85,   1.70786E-08
                  -26,      3,    85,   1.70786E-08
                  -27,      4,    85,   1.70786E-08
                  -28,      5,    85,   1.70786E-08
                  -29,      6,    85,   1.70786E-08
                  -30,      7,    85,   1.70786E-08
                  -31,      8,    85,   1.70786E-08
                  -32,      9,    85,   1.70786E-08
                  -33,     10,    85,   1.70786E-08
                  -34,     11,    85,   1.70786E-08
                  -35,     12,    85,   1.70786E-08
                  -36,     13,    85,   1.70786E-08
                  -37,     14,    85,   1.70786E-08
                  -38,     15,    85,   1.70786E-08
                  -39,     16,    85,   1.70786E-08
                  -40,     17,    85,   1.70786E-08
                  -41,     18,    85,   1.70786E-08
-42, 39, 85, .1713E-6*156.8$
GEN -43, 18, 1, 40, 1, 85, 0, .1713E-8, 1., 6.140, 1.$
                  -43,     40,    85,   1.05173E-08
                  -44,     41,    85,   1.05173E-08
                  -45,     42,    85,   1.05173E-08
                  -46,     43,    85,   1.05173E-08
                  -47,     44,    85,   1.05173E-08
                  -48,     45,    85,   1.05173E-08
                  -49,     46,    85,   1.05173E-08
```

```
 22    06/13/73.  NEW
 23    06/13/73.  NEW
 24    06/13/73.  NEW
 25    06/13/73.  NEW
 26    06/13/73.  NEW
 27    06/13/73.  NEW

 28    06/13/73.  NEW
 29    06/13/73.  NEW
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             -50,     47,     85,  1.05173E-08
             -51,     48,     85,  1.05173E-08
             -52,     49,     85,  1.05173E-08
             -53,     50,     85,  1.05173E-08
             -54,     51,     85,  1.05173E-08
             -55,     52,     85,  1.05173E-08
             -56,     53,     85,  1.05173E-08
             -57,     54,     85,  1.05173E-08
             -58,     55,     85,  1.05173E-08
             -59,     56,     85,  1.05173E-08
             -60,     57,     85,  1.05173E-08
GEN -61, 18, 1, 58, 1, 85, 0, .1713E-8,  1., 2.+3 , 1.$            30    06/13/73.  NEW
             -61,     58,     85,  4.26537E-09
             -62,     59,     85,  4.26537E-09
             -63,     60,     85,  4.26537E-09
             -64,     61,     85,  4.26537E-09
             -65,     62,     85,  4.26537E-09
             -66,     63,     85,  4.26537E-09
             -67,     64,     85,  4.26537E-09
             -68,     65,     85,  4.26537E-09
             -69,     66,     85,  4.26537E-09
             -70,     67,     85,  4.26537E-09
             -71,     68,     85,  4.26537E-09
             -72,     69,     85,  4.26537E-09
             -73,     70,     85,  4.26537E-09
             -74,     71,     85,  4.26537E-09
             -75,     72,     85,  4.26537E-09
             -76,     73,     85,  4.26537E-09
             -77,     74,     85,  4.26537E-09
             -78,     75,     85,  4.26537E-09
-79,176, 85, .1713E-8*71.$                                          31    06/13/73.  NEW
-80,137, 85, .1713E-8*71.$                                          32    06/13/73.  NEW
-81, 79, 76, .1713E-8*.17150*339.$                                  33    06/13/73.  NEW
-82, 79, 77, .1713E-8*.37000*339.$                                  34    06/13/73.  NEW
-300, 76, 77, .1713E-8*.1929*72.$                                   35    06/13/73.  NEW
GEN -83, 18, 1, 58, 1, 79, 0, .1713E-8, .03735, 339., 1.$           36    06/13/73.  NEW
             -83,     58,     79,  4.26820E-09
             -84,     59,     79,  4.26820E-09
             -85,     60,     79,  4.26820E-09
             -86,     61,     79,  4.26820E-09
             -87,     62,     79,  4.26820E-09
             -88,     63,     79,  4.26820E-09
             -89,     64,     79,  4.26820E-09
             -90,     65,     79,  4.26820E-09
             -91,     66,     79,  4.26820E-09
             -92,     67,     79,  4.26820E-09
             -93,     68,     79,  4.26820E-09
             -94,     69,     79,  4.26820E-09
             -95,     70,     79,  4.26820E-09
             -96,     71,     79,  4.26820E-09
             -97,     72,     79,  4.26820E-09
             -98,     73,     79,  4.26820E-09
             -99,     74,     79,  4.26820E-09
             -100,    75,     79,  4.26820E-09
GEN -101, 18, 1, 40, 1, 79, 0, .1713E-8, .018100, 339., 1.$         37    06/13/73.  NEW
             -101,    40,     79,  1.05103E-08
             -102,    41,     79,  1.05103E-08
             -103,    42,     79,  1.05103E-08
             -104,    43,     79,  1.05103E-08
             -105,    44,     79,  1.05103E-08
             -106,    45,     79,  1.05103E-08
             -107,    46,     79,  1.05103E-08
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                 -108,     47,     79,   1.05108E-08
                 -109,     48,     79,   1.05108E-08
                 -110,     49,     79,   1.05108E-08
                 -111,     50,     79,   1.05108E-08
                 -112,     51,     79,   1.05108E-08
                 -113,     52,     79,   1.05108E-08
                 -114,     53,     79,   1.05108E-08
                 -115,     54,     79,   1.05108E-08
                 -116,     55,     79,   1.05108E-08
                 -117,     56,     79,   1.05108E-08
                 -118,     57,     79,   1.05108E-08
-119, 37, 80, .1713E-8*.174700*412.$                              38    06/13/73.  NEW
-120, 38, 80, .1713E-8*.33900*412.$                               39    06/13/73.  NEW
GEN -121, 18, 1, 1, 1, 80, 0, .1713E-8, .126970, 412., 1.$        40    06/13/73.  NEW
                 -121,      1,     80,   1.90342E-08
                 -122,      2,     80,   1.90342E-08
                 -123,      3,     80,   1.90342E-08
                 -124,      4,     80,   1.90342E-08
                 -125,      5,     80,   1.90342E-08
                 -126,      6,     80,   1.90342E-08
                 -127,      7,     80,   1.90342E-08
                 -128,      8,     80,   1.90342E-08
                 -129,      9,     80,   1.90342E-08
                 -130,     10,     80,   1.90342E-08
                 -131,     11,     80,   1.90342E-08
                 -132,     12,     80,   1.90342E-08
                 -133,     13,     80,   1.90342E-08
                 -134,     14,     80,   1.90342E-08
                 -135,     15,     80,   1.90342E-08
                 -136,     16,     80,   1.90342E-08
                 -137,     17,     80,   1.90342E-08
                 -138,     18,     80,   1.90342E-08
END                                                               41    06/13/73.  NEW
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REL. COND. NO.	ACTUAL CONDUCTOR NUMBERS 1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1 - 20	1	3	5	214	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
21 - 40	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
41 - 60	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
61 - 80	80	81	82	300	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
81 - 100	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
101 - 120	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138

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BCD 3CONSTANTS DATA                                               42    06/13/73.  NEW
NDSIOR=700                                                        43    06/13/73.  NEW
DTIMEI=.05                                                        44    06/13/73.  NEW
OUTPUT=.5                                                         45    06/13/73.  NEW
TIMEND=10.                                                        46    06/13/73.  NEW
DRLXCA=.01                                                        47    06/13/73.  NEW
ARLXCA=.01                                                        48    06/13/73.  NEW
NLOOP=100                                                         49    06/13/73.  NEW
TIMEO=0.                                                          50    06/13/73.  NEW
1=.07  $  OSR SOLAR ABSORPTIVITY                                  51    06/13/73.  NEW
2=.7   $  OSR EMISSIVITY                                          52    06/13/73.  NEW
3=.2   $ EXTERNAL COVER SOLAR ABSORPTIVITY                        53    06/13/73.  NEW
4=.29  $ EXTERNAL COVER EMISSIVITY                                54    06/13/73.  NEW
5=0.$ 0. FOR INITIAL STDSTL, 1. FOR INITIAL FWDBCK                55    06/13/73.  NEW
END                                                               56    06/13/73.  NEW
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REL. CONST. NO.                                    ACTUAL CONSTANT NUMBERS
                  1    2    3    4    5    6    7    8    9    10    1    2    3    4    5    6    7    8    9    10
   1 -    5    1    2    3    4    5

        300 BARRAY DATA                                                                    57    06/13/73.  NEW
        100$SOLAR INCIDENT HEAT FLUX, BTU/HR SQ FT                                         58    06/13/73.  NEW
        443., 396., 294., 156., 40., 0., REPEAT, 9, 40., 156., 294., 396., 443.            59    06/13/73.  NEW
        END $                                                                              60    06/13/73.  NEW
        101 $ PLANETARY INCIDENT HEAT FLUX, BTU/HR SQ FT                                   61    06/13/73.  NEW
        5.3, 1.75, 0., REPEAT, 5, 1.75, 5.3, 17.85, 28.4, 39.9, 48., 52.1, 48.             62    06/13/73.  NEW
        39.9, 28.4, 17.85                                                                  63    06/13/73.  NEW
        END                                                                                64    06/13/73.  NEW
        102 $ TIME ARRAY FOR PROPELLANT USEAGE                                             65    06/13/73.  NEW
        0., 100.$                                                                          66    06/13/73.  NEW
        END $                                                                              67    06/13/73.  NEW
        103 $ OXIDIZER WEIGHT                                                              68    06/13/73.  NEW
        6550., 6550.$                                                                      69    06/13/73.  NEW
        END $                                                                              70    06/13/73.  NEW
        104 $ FUEL WEIGHT                                                                  71    06/13/73.  NEW
        3275., 3275.$                                                                      72    06/13/73.  NEW
        END $                                                                              73    06/13/73.  NEW
         2,SPACE, 360, END $ NODE 18                                                       74    06/13/73.  NEW
         4,SPACE, 360, END $ NODE 57                                                       75    06/13/73.  NEW
         5,SPACE, 360, END $ NODE 75                                                       76    06/13/73.  NEW
         6,SPACE, 360, END $ NODE  9                                                       77    06/13/73.  NEW
         8,SPACE, 360, END $ NODE 48                                                       78    06/13/73.  NEW
         9,SPACE, 360, END $ NODE 66                                                       79    06/13/73.  NEW
        10,SPACE, 360, END $ NODE  5                                                       80    06/13/73.  NEW
        12,SPACE, 360, END $ NODE 44                                                       81    06/13/73.  NEW
        13,SPACE, 360, END $ NODE 62                                                       82    06/13/73.  NEW
        14,SPACE, 360, END $ NODE 14                                                       83    06/13/73.  NEW
        16,SPACE, 360, END $ NODE 53                                                       84    06/13/73.  NEW
        17,SPACE, 360, END $ NODE 71                                                       85    06/13/73.  NEW
        18,SPACE, 360, END $ NODE 38                                                       86    06/13/73.  NEW
        19,SPACE, 360, END $ NODE 39                                                       87    06/13/73.  NEW
        20,SPACE, 360, END $ NODE 77                                                       88    06/13/73.  NEW
        21,SPACE, 360, END $ NODE 78                                                       89    06/13/73.  NEW
        22,SPACE, 360, END $ NODE 37                                                       90    06/13/73.  NEW
        23,SPACE, 360, END $ NODE 76                                                       91    06/13/73.  NEW
        24,SPACE, 360, END $ NODE 51                                                       92    06/13/73.  NEW
        25,SPACE, 360, END $ NODE 52                                                       93    06/13/73.  NEW
        37,SPACE, 360, END $ TIMEN                                                         94    06/13/73.  NEW
        52, SPACE, 360, END $ NODE 137                                                     95    06/13/73.  NEW
        53, SPACE, 360, END $ NODE 176                                                     96    06/13/73.  NEW
        59, SPACE, 360, END $ NODE 79                                                      97    06/13/73.  NEW
        60, SPACE, 360, END $ NODE 80                                                      98    06/13/73.  NEW
        61, SPACE, 360, END $ NODE 80 CAPACITY                                             99    06/13/73.  NEW
        62, SPACE, 360, END $ NODE 81 CAPACITY                                            100    06/13/73.  NEW
        63, SPACE, 360, END $ NODE 82 CAPACITY                                            101    06/13/73.  NEW
   C  PLOT TITLES                                                                         102    06/13/73.  NEW
        29 $ PLOT 1                                                                       103    06/13/73.  NEW
        320 9 TEMPERATURE OF NODES  5,  9, 14, 18                                         104    06/13/73.  NEW
        300 3                                                                             105    06/13/73.  NEW
        END                                                                               106    06/13/73.  NEW
        30 $ PLOT 3                                                                       107    06/13/73.  NEW
        320 9 TEMPERATURE OF NODES 44, 43, 53, 57                                         108    06/13/73.  NEW
        300 3                                                                             109    06/13/73.  NEW
        END                                                                               110    06/13/73.  NEW
        31 $ PLOT 4                                                                       111    06/13/73.  NEW
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BCD 9 TEMPERATURE OF NODES 62, 66, 71, 75                          112   06/13/73.  NEW
BCD 3                                                              113   06/13/73.  NEW
END                                                                114   06/13/73.  NEW
32 $ PLOT 5                                                        115   06/13/73.  NEW
BCD 9 TEMPERATURE OF NODES 38, 39, 77, 78                          116   06/13/73.  NEW
BCD 3                                                              117   06/13/73.  NEW
END                                                                118   06/13/73.  NEW
33 $ PLOT 6                                                        119   06/13/73.  NEW
BCD 9 TEMPERATURE OF NODES 37, 76                                  120   06/13/73.  NEW
BCD 3                                                              121   06/13/73.  NEW
END                                                                122   06/13/73.  NEW
34 $ PLOT 7                                                        123   06/13/73.  NEW
BCD 9 TEMPERATURE OF NODES 81, 82                                  124   06/13/73.  NEW
BCD 3                                                              125   06/13/73.  NEW
END                                                                126   06/13/73.  NEW
38 $ PLOT 14                                                       127   06/13/73.  NEW
BCD 9 TEMPERATURE OF NODES 137, 175                                128   06/13/73.  NEW
BCD 3                                                              129   06/13/73.  NEW
END                                                                130   06/13/73.  NEW
38 $ X AXIS                                                        131   06/13/73.  NEW
BCD 9 TIME, HOURS                                                  132   06/13/73.  NEW
BCD 3                                                              133   06/13/73.  NEW
END                                                                134   06/13/73.  NEW
39 $ Y AXIS                                                        135   06/13/73.  NEW
BCD 9 TEMPERATURE, DEGF                                            136   06/13/73.  NEW
BCD 3                                                              137   06/13/73.  NEW
END                                                                138   06/13/73.  NEW
54 $                                                               139   06/13/73.  NEW
BCD 9 TEMPERATURE OF NODES 79, 80                                  140   06/13/73.  NEW
BCD 3                                                              141   06/13/73.  NEW
END                                                                142   06/13/73.  NEW
55 $                                                               143   06/13/73.  NEW
BCD 9 CAPACITY OF NODES 80, 81, 82                                 144   06/13/73.  NEW
BCD 3                                                              145   06/13/73.  NEW
END                                                                146   06/13/73.  NEW
56 $                                                               147   06/13/73.  NEW
BCD 9 CAPACITY, BTU/DEGF                                           148   06/13/73.  NEW
BCD 3                                                              149   06/13/73.  NEW
END                                                                150   06/13/73.  NEW
END                                                                151   06/13/73.  NEW
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RELATIVE ARRAY NO.	ACTUAL ARRAY NO.	STARTING LOCATION	NUMBER OF ELEMENTS
1	100	1	19
2	101	21	19
3	102	39	3
4	103	42	3
5	104	45	3
6	2	48	361
7	4	409	361
8	5	770	361
9	6	1131	361
10	8	1492	361
11	9	1853	361
12	10	2214	361
13	12	2575	361
14	13	2936	361
15	14	3297	361
16	16	3658	361
17	17	4019	361
18	18	4380	361
19	19	4741	361
20	20	5102	361

21	21	5463	361
22	22	5824	361
23	23	6185	361
24	24	6546	361
25	25	6907	361
26	37	7268	361
27	52	7629	361
28	53	7990	361
29	59	8351	361
30	60	8712	361
31	61	9073	361
32	62	9434	361
33	63	9795	361
34	28	10156	13
35	30	10169	13
36	31	10182	13
37	32	10195	13
38	33	10208	13
39	34	10221	13
40	58	10234	13
41	38	10247	13
42	39	10260	13
43	64	10273	13
44	65	10286	13
45	66	10299	13

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      BDD BEXECUTION                                                    152    06/13/73.  NEW
      JTEST=0                                                           153    06/13/73.  NEW
      DO 5 I=1,18                                                       154    06/13/73.  NEW
      S24+I-1=S24+I-1 * P4                                              155    06/13/73.  NEW
      S43+I-1=S43+I-1 * P4                                              156    06/13/73.  NEW
 5    S61+I-1=S61+I-1 * R2                                              157    06/13/73.  NEW
      S42=S42 * R4                                                      158    06/13/73.  NEW
      S79=S79 * P4                                                      159    06/13/73.  NEW
      S80=S80 * R4                                                      160    06/13/73.  NEW
      OUTPUT=0.                                                         161    06/13/73.  NEW
      TIMEND=0.                                                         162    06/13/73.  NEW
      NLOOP=500                                                         163    06/13/73.  NEW
      BALENG=.5                                                         164    06/13/73.  NEW
      R5=0.                                                             165    06/13/73.  NEW
      STOSTL                                                            166    06/13/73.  NEW
      QMAP(3HALL)                                                       167    06/13/73.  NEW
      OUTPUT=.5                                                         168    06/13/73.  NEW
      TIMEND=100.                                                       169    06/13/73.  NEW
      BALENG=0.                                                         170    06/13/73.  NEW
      NLOOP=100                                                         171    06/13/73.  NEW
      TIMEO=0.                                                          172    06/13/73.  NEW
      DTIMEI=.05                                                        173    06/13/73.  NEW
      R5=1.                                                             174    06/13/73.  NEW
      DO 15 I=1,18                                                      175    06/13/73.  NEW
      A100+I=0.                                                         176    06/13/73.  NEW
 15   A101+I=0.                                                         177    06/13/73.  NEW
      FWDBCK                                                            178    06/13/73.  NEW
      OPNPLT                                                            179    06/13/73.  NEW
      PLOTX2(-1, 0., 168., -49., 193., 44, A38+1, A39+1, A28+1, -JTEST, A37+1,   180    06/13/73.  NEW
     . A10+1)$                                                          181    06/13/73.  NEW
      PLOTX2( 0, 0., 168., -49., 193., 44, A38+1, A39+1, A28+1, -JTEST, A37+1,   182    06/13/73.  NEW
     . A 6+1)$                                                          183    06/13/73.  NEW
      PLOTX2( 0, 0., 168., -49., 193., 44, A38+1, A39+1, A28+1, -JTEST, A37+1,   184    06/13/73.  NEW
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     A14+1)$                                                                185   06/13/73.  NEW
 PLOTX2( 0, 0., 168., -49., 199., 4., A38+1, A39+1, A28+1, -JTEST, A37+1,   186   06/13/73.  NEW
     A 2+1)$                                                                187   06/13/73.  NEW
 PLOTX2(-1, 0., 168., -49., 199., 4., A38+1, A39+1, A30+1, -JTEST, A37+1,   188   06/13/73.  NEW
     A12+1)$                                                                189   06/13/73.  NEW
 PLOTX2( 0, 0., 168., -49., 199., 4., A38+1, A39+1, A30+1, -JTEST, A37+1,   190   06/13/73.  NEW
     A 6+1)$                                                                191   06/13/73.  NEW
 PLOTX2( 0, 0., 168., -49., 199., 4., A38+1, A39+1, A30+1, -JTEST, A37+1,   192   06/13/73.  NEW
     A16+1)$                                                                193   06/13/73.  NEW
 PLOTX2( 0, 0., 168., -49., 199., 4., A38+1, A39+1, A30+1, -JTEST, A37+1,   194   06/13/73.  NEW
     A 4+1)$                                                                195   06/13/73.  NEW
 PLOTX2(-1, 0., 168., -49., 199., 4., A38+1, A39+1, A31+1, -JTEST, A37+1,   196   06/13/73.  NEW
     A13+1)$                                                                197   06/13/73.  NEW
 PLOTX2( 0, 0., 168., -49., 199., 4., A38+1, A39+1, A31+1, -JTEST, A37+1,   198   06/13/73.  NEW
     A 9+1)$                                                                199   06/13/73.  NEW
 PLOTX2( 0, 0., 168., -49., 199., 4., A38+1, A39+1, A31+1, -JTEST, A37+1,   200   06/13/73.  NEW
     A17+1)$                                                                201   06/13/73.  NEW
 PLOTX2( 0, 0., 168., -49., 199., 4., A38+1, A39+1, A31+1, -JTEST, A37+1,   202   06/13/73.  NEW
     A 5+1)$                                                                203   06/13/73.  NEW
 PLOTX2(-1, 0., 168.,   0.,  99., 4., A38+1, A39+1, A32+1, -JTEST, A37+1,   204   06/13/73.  NEW
     A18+1)$                                                                205   06/13/73.  NEW
 PLOTX2( 0, 0., 168.,   0.,  99., 4., A38+1, A39+1, A32+1, -JTEST, A37+1,   206   06/13/73.  NEW
     A19+1)$                                                                207   06/13/73.  NEW
 PLOTX2( 0, 0., 168.,   0.,  99., 4., A38+1, A39+1, A32+1, -JTEST, A37+1,   208   06/13/73.  NEW
     A20+1)$                                                                209   06/13/73.  NEW
 PLOTX2( 0, 0., 168.,   0.,  99., 4., A38+1, A39+1, A32+1, -JTEST, A37+1,   210   06/13/73.  NEW
     A21+1)$                                                                211   06/13/73.  NEW
 PLOTX2(-1, 0., 168.,   0.,  99., 4., A38+1, A39+1, A33+1, -JTEST, A37+1,   212   06/13/73.  NEW
     A22+1)$                                                                213   06/13/73.  NEW
 PLOTX2( 0, 0., 168.,   0.,  99., 4., A38+1, A39+1, A33+1, -JTEST, A37+1,   214   06/13/73.  NEW
     A23+1)$                                                                215   06/13/73.  NEW
 PLOTX2(-1, 0., 168.,   0.,  99., 4., A38+1, A39+1, A34+1, -JTEST, A37+1,   216   06/13/73.  NEW
     A24+1)$                                                                217   06/13/73.  NEW
 PLOTX2( 0, 0., 168.,   0.,  99., 4., A38+1, A39+1, A34+1, -JTEST, A37+1,   218   06/13/73.  NEW
     A25+1)$                                                                219   06/13/73.  NEW
 PLOTX2(-1, 0., 168., -249., 249., 4., A38+1, A39+1, A58+1, -JTEST, A37+1,  220   06/13/73.  NEW
     A52+1) $                                                               221   06/13/73.  NEW
 PLOTX2( 0, 0., 168., -249., 249., 4., A38+1, A39+1, A58+1, -JTEST, A37+1,  222   06/13/73.  NEW
     A53+1) $                                                               223   06/13/73.  NEW
 PLOTX2(-1, 0., 168., 1.,   99., 4., A38+1, A39+1, A64+1, -JTEST, A37+1,    224   06/13/73.  NEW
     A59+1)$                                                                225   06/13/73.  NEW
 PLOTX2( 0, 0., 168., 1.,   99., 4., A38+1, A39+1, A64+1, -JTEST, A37+1,    226   06/13/73.  NEW
     A60+1)$                                                                227   06/13/73.  NEW
 PLOTX2(-1, 0., 168., 0., 9.9E3, 4., A38+1, A66+1, A65+1, -JTEST, A37+1,    228   06/13/73.  NEW
     A61+1)$                                                                229   06/13/73.  NEW
 PLOTX2( 0, 0., 168., 0., 9.9E3, 4., A38+1, A66+1, A65+1, -JTEST, A37+1,    230   06/13/73.  NEW
     A62+1)$                                                                231   06/13/73.  NEW
 PLOTX2( 0, 0., 168., 0., 9.9E3, 4., A38+1, A66+1, A65+1, -JTEST, A37+1,    232   06/13/73.  NEW
     A63+1)$                                                                233   06/13/73.  NEW
 PLTND                                                                      234   06/13/73.  NEW
 END                                                                        235   06/13/73.  NEW
 300 3VARIABLES 1                                                           236   06/13/73.  NEW
 IF(P5.LT..5)GO TO 5                                                        237   06/13/73.  NEW
C     INSERT CONSUMABLES CAPACITY ADJUSTMENT                                238   06/13/73.  NEW
5     DO 10 I=1, 18                                                         239   06/13/73.  NEW
        Q1+I-1=(A100+I*R3+A101+I*P4)*11.12                                  240   06/13/73.  NEW
       Q39=Q 39 + (A100+I * R3 + A101+I * R4)*8.70                          241   06/13/73.  NEW
       Q40+I-1 = (A100+I * R3 + A101+I * R4)*5.14                           242   06/13/73.  NEW
10    Q58+I-1 = (A100+I * R1 + A101+I * R2)*2.49                            243   06/13/73.  NEW
      Q176=Q137=13.*72.* R4                                                 244   06/13/73.  NEW
      Q179=2750. $ AVIONICS HEAT DISSIPATION                                245   06/13/73.  NEW
      D11MDA(TIMEN, A102, A103, .37, C82)                                   246   06/13/73.  NEW
```

```
      Q11MDA(TIMEN, Q102, Q104, .7, C81)                              06/13/73.  NEW
      IF(TIMEN.GT..01)RETURN                                          06/13/73.  NEW
C DE-BUG                                                              06/13/73.  NEW
      WRITE(NOUT,1001) (Q1+I-1,I=1,18),                               06/13/73.  NEW
     . (Q 40+I-1,I=1,18) , (Q58+I-1,I=1,13), Q137, Q176               06/13/73.  NEW
F1001 FORMAT(1X,10F10.3)                                              06/13/73.  NEW
      WRITE(NOUT,1001)C82,C81                                         06/13/73.  NEW
      END                                                             06/13/73.  NEW
      BCD 3VARIABLES 2                                                06/13/73.  NEW
      END                                                             06/13/73.  NEW
      BCD 3OUTPUT CALLS                                               06/13/73.  NEW
      TPRINT                                                          06/13/73.  NEW
      JTEST=JTEST+1                                                   06/13/73.  NEW
      Q 2 + JTEST = T18                                               06/13/73.  NEW
      Q 4 + JTEST = T57                                               06/13/73.  NEW
      Q 5 + JTEST = T75                                               06/13/73.  NEW
      Q 6 + JTEST = T 9                                               06/13/73.  NEW
      Q 8 + JTEST = T48                                               06/13/73.  NEW
      Q 9 + JTEST = T66                                               06/13/73.  NEW
      Q10 + JTEST = T 5                                               06/13/73.  NEW
      Q12 + JTEST = T44                                               06/13/73.  NEW
      Q13 + JTEST = T62                                               06/13/73.  NEW
      Q14 + JTEST = T14                                               06/13/73.  NEW
      Q16 + JTEST = T53                                               06/13/73.  NEW
      Q17 + JTEST = T71                                               06/13/73.  NEW
      Q18 + JTEST = T38                                               06/13/73.  NEW
      Q19 + JTEST = T39                                               06/13/73.  NEW
      Q20 + JTEST = T77                                               06/13/73.  NEW
      Q21 + JTEST = T78                                               06/13/73.  NEW
      Q22 + JTEST = T37                                               06/13/73.  NEW
      Q23 + JTEST = T76                                               06/13/73.  NEW
      Q24 + JTEST = T81                                               06/13/73.  NEW
      Q25 + JTEST = T82                                               06/13/73.  NEW
      Q37 + JTEST = TIMEN                                             06/13/73.  NEW
      Q52 + JTEST = T137                                              06/13/73.  NEW
      Q53 + JTEST = T176                                              06/13/73.  NEW
      Q59 + JTEST = T79                                               06/13/73.  NEW
      Q60 + JTEST = T80                                               06/13/73.  NEW
      Q61 + JTEST = C80                                               06/13/73.  NEW
      Q62 + JTEST = C81                                               06/13/73.  NEW
      Q63 + JTEST = C82                                               06/13/73.  NEW
      IF(T81.LT.-62.5.OR.T82.LT.11.3)TIMEND=TIMEN                     06/13/73.  NEW
      END                                                             06/13/73.  NEW
      BCD 3END OF DATA                                                06/13/73.  NEW

INITIAL CONDITIONS HAVE BEEN STORED ON TAPE 22, SO RESTART OF INITIAL CONDITIONS CAN BE PERFORMED.
 THE RESTART NAME IS ST0000
```

Table C-2 MITAS Input for Tug Thermal Model without MLI

NOT RECALL

```
BCD 3THERMAL LPCS                                                     1   06/16/73.  NEW
BCD 9 CONFIG 2,MLI,NO PAD,LONG AXIS TOWARD SUN                        2   06/16/73.  NEW
END                                                                   3   06/16/73.  NEW
BCD 3NODE DATA                                                        4   06/16/73.  NEW
GEN 1, 18, 1, 70., 1.81, 1., 1., 1.$                                  5   06/16/73.  NEW
                 1,  7.00000E+01,  1.81000E+00
                 2,  7.00000E+01,  1.81000E+00
                 3,  7.00000E+01,  1.81000E+00
                 4,  7.00000E+01,  1.81000E+00
                 5,  7.00000E+01,  1.81000E+00
                 6,  7.00000E+01,  1.81000E+00
                 7,  7.00000E+01,  1.81000E+00
                 8,  7.00000E+01,  1.81000E+00
                 9,  7.00000E+01,  1.81000E+00
                10,  7.00000E+01,  1.81000E+00
                11,  7.00000E+01,  1.81000E+00
                12,  7.00000E+01,  1.81000E+00
                13,  7.00000E+01,  1.81000E+00
                14,  7.00000E+01,  1.81000E+00
                15,  7.00000E+01,  1.81000E+00
                16,  7.00000E+01,  1.81000E+00
                17,  7.00000E+01,  1.81000E+00
                18,  7.00000E+01,  1.81000E+00
39, 70., 18.5$                                                        6   06/16/73.  NEW
GEN 40, 18, 1, 70., 1.112, 1., 1., 1.$                                7   06/16/73.  NEW
                40,  7.00000E+01,  1.11200E+00
                41,  7.00000E+01,  1.11200E+00
                42,  7.00000E+01,  1.11200E+00
                43,  7.00000E+01,  1.11200E+00
                44,  7.00000E+01,  1.11200E+00
                45,  7.00000E+01,  1.11200E+00
                46,  7.00000E+01,  1.11200E+00
                47,  7.00000E+01,  1.11200E+00
                48,  7.00000E+01,  1.11200E+00
                49,  7.00000E+01,  1.11200E+00
                50,  7.00000E+01,  1.11200E+00
                51,  7.00000E+01,  1.11200E+00
                52,  7.00000E+01,  1.11200E+00
                53,  7.00000E+01,  1.11200E+00
                54,  7.00000E+01,  1.11200E+00
                55,  7.00000E+01,  1.11200E+00
                56,  7.00000E+01,  1.11200E+00
                57,  7.00000E+01,  1.11200E+00
GEN 58, 13, 1, 70., .451, 1., 1., 1.$                                 8   06/16/73.  NEW
                58,  7.00000E+01,  4.51000E-01
                59,  7.00000E+01,  4.51000E-01
                60,  7.00000E+01,  4.51000E-01
                61,  7.00000E+01,  4.51000E-01
                62,  7.00000E+01,  4.51000E-01
                63,  7.00000E+01,  4.51000E-01
                64,  7.00000E+01,  4.51000E-01
                65,  7.00000E+01,  4.51000E-01
                66,  7.00000E+01,  4.51000E-01
                67,  7.00000E+01,  4.51000E-01
                68,  7.00000E+01,  4.51000E-01
                69,  7.00000E+01,  4.51000E-01
                70,  7.00000E+01,  4.51000E-01
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                         71,   7.00000E+01,   4.51000E-01
                         72,   7.00000E+01,   4.51000E-01
                         73,   7.00000E+01,   4.51000E-01
                         74,   7.00000E+01,   4.51000E-01
                         75,   7.00000E+01,   4.51000E-01
78, 70., 12.32$                                                              9    06/16/73.  NEW
79, 70., 70.8$                                                              10    06/16/73.  NEW
30, 70., 600.$                                                              11    06/16/73.  NEW
31, 70., 1.$                                                                12    06/16/73.  NEW
32, 70., 1.$                                                                13    06/16/73.  NEW
33, 70., 9.343                                                              14    06/16/73.  NEW
77, 70., 16.58$                                                             15    06/16/73.  NEW
37, 70., -1.$                                                               16    06/16/73.  NEW
75, 70., -1.$                                                               17    06/16/73.  NEW
GEN 101, 18, 1, 70., 1., 1., 1., -1.$                                       18    06/16/73.  NEW
                        101,   7.00000E+01, -1.00000E+00
                        102,   7.00000E+01, -1.00000E+00
                        103,   7.00000E+01, -1.00000E+00
                        104,   7.00000E+01, -1.00000E+00
                        105,   7.00000E+01, -1.00000E+00
                        106,   7.00000E+01, -1.00000E+00
                        107,   7.00000E+01, -1.00000E+00
                        108,   7.00000E+01, -1.00000E+00
                        109,   7.00000E+01, -1.00000E+00
                        110,   7.00000E+01, -1.00000E+00
                        111,   7.00000E+01, -1.00000E+00
                        112,   7.00000E+01, -1.00000E+00
                        113,   7.00000E+01, -1.00000E+00
                        114,   7.00000E+01, -1.00000E+00
                        115,   7.00000E+01, -1.00000E+00
                        116,   7.00000E+01, -1.00000E+00
                        117,   7.00000E+01, -1.00000E+00
                        118,   7.00000E+01, -1.00000E+00
139, 70., -1.$                                                              19    06/16/73.  NEW
GEN 140, 18, 1, 70., 1., 1., 1., -1.0$                                      20    06/16/73.  NEW
                        140,   7.00000E+01, -1.00000E+00
                        141,   7.00000E+01, -1.00000E+00
                        142,   7.00000E+01, -1.00000E+00
                        143,   7.00000E+01, -1.00000E+00
                        144,   7.00000E+01, -1.00000E+00
                        145,   7.00000E+01, -1.00000E+00
                        146,   7.00000E+01, -1.00000E+00
                        147,   7.00000E+01, -1.00000E+00
                        148,   7.00000E+01, -1.00000E+00
                        149,   7.00000E+01, -1.00000E+00
                        150,   7.00000E+01, -1.00000E+00
                        151,   7.00000E+01, -1.00000E+00
                        152,   7.00000E+01, -1.00000E+00
                        153,   7.00000E+01, -1.00000E+00
                        154,   7.00000E+01, -1.00000E+00
                        155,   7.00000E+01, -1.00000E+00
                        156,   7.00000E+01, -1.00000E+00
                        157,   7.00000E+01, -1.00000E+00
137, 70., -1.$                                                              21    06/16/73.  NEW
176, 70., -1.$                                                              22    06/16/73.  NEW
-95, -460., 1.$                                                             23    06/16/73.  NEW
END                                                                         24    06/16/73.  NEW
```

ACTUAL NODE NUMBERS

REL. NODE NO.	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1 - 20	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	39	40
21 - 40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60

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 41 -    50    61    62    63    64    65    66    67    68    69    70    71    72    73    74    75    78    79    80    81    82
 61 -    30    38    77    37    76   101   102   103   104   105   106   107   108   109   110   111   112   113   114   115   116
 81 -   100   117   118   139   140   141   142   143   144   145   146   147   148   149   150   151   152   153   154   155   156
101 -   104   157   137   176    85


    BCD 3CONDUCTOR DATA                                                        25    06/16/73.  NEW
    1, 77,82, 78, 82, 42.1$                                                    26    06/16/73.  NEW
    3, 78,31, 38,81, 42.1$                                                     27    06/16/73.  NEW
    5, 39, 81, 46.6$                                                           28    06/16/73.  NEW
    195, 39, 139, 7.E-4*156.8/.08333                                           29    06/16/73.  NEW
    214, 76, 176, 37, 137, 7.E-4*72./.08333$                                   30    06/16/73.  NEW
    GEN 177, 18, 1,  1, 1, 101, 1, .0935   , 1.00, 1., 1.$                     31    06/16/73.  NEW
                   177,     1,    101,  9.35000E-02
                   178,     2,    102,  9.35000E-02
                   179,     3,    103,  9.35000E-02
                   180,     4,    104,  9.35000E-02
                   181,     5,    105,  9.35000E-02
                   182,     6,    106,  9.35000E-02
                   183,     7,    107,  9.35000E-02
                   184,     8,    108,  9.35000E-02
                   185,     9,    109,  9.35000E-02
                   186,    10,    110,  9.35000E-02
                   187,    11,    111,  9.35000E-02
                   188,    12,    112,  9.35000E-02
                   189,    13,    113,  9.35000E-02
                   190,    14,    114,  9.35000E-02
                   191,    15,    115,  9.35000E-02
                   192,    16,    116,  9.35000E-02
                   193,    17,    117,  9.35000E-02
                   194,    18,    118,  9.35000E-02
    GEN  196, 18, 1, 40, 1, 140, 1, .0516   ,1.000, 1., 1.$                    32    06/16/73.  NEW
                   196,    40,    140,  5.16000E-02
                   197,    41,    141,  5.16000E-02
                   198,    42,    142,  5.16000E-02
                   199,    43,    143,  5.16000E-02
                   200,    44,    144,  5.16000E-02
                   201,    45,    145,  5.16000E-02
                   202,    46,    146,  5.16000E-02
                   203,    47,    147,  5.16000E-02
                   204,    48,    148,  5.16000E-02
                   205,    49,    149,  5.16000E-02
                   206,    50,    150,  5.16000E-02
                   207,    51,    151,  5.16000E-02
                   208,    52,    152,  5.16000E-02
                   209,    53,    153,  5.16000E-02
                   210,    54,    154,  5.16000E-02
                   211,    55,    155,  5.16000E-02
                   212,    56,    156,  5.16000E-02
                   213,    57,    157,  5.16000E-02
    GEN -24, 18, 1,101, 1, 85, 0, .1713E-8,  1., 9.970, 1.$                    33    06/16/73.  NEW
                   -24,   101,     85,  1.70786E-08
                   -25,   102,     85,  1.70786E-08
                   -26,   103,     85,  1.70786E-08
                   -27,   104,     85,  1.70786E-08
                   -28,   105,     85,  1.70786E-08
                   -29,   106,     85,  1.70786E-08
                   -30,   107,     85,  1.70786E-08
                   -31,   108,     85,  1.70786E-08
                   -32,   109,     85,  1.70786E-08
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                -33,    110,    85,  1.70786E-08
                -34,    111,    85,  1.70786E-08
                -35,    112,    85,  1.70786E-08
                -36,    113,    85,  1.70786E-08
                -37,    114,    85,  1.70786E-08
                -38,    115,    85,  1.70786E-08
                -39,    116,    85,  1.70786E-08
                -40,    117,    85,  1.70786E-08
                -41,    118,    85,  1.70786E-08
-42, 139, 85, .1713E-8*156.8$                                          34    06/16/73.  NEW
GEN -43, 18, 1,140, 1, 85, 0, .1713E-8,  1., 6.149, 1.$                35    06/16/73.  NEW
                -43,    140,    85,  1.05173E-08
                -44,    141,    85,  1.05173E-08
                -45,    142,    85,  1.05173E-08
                -46,    143,    85,  1.05173E-08
                -47,    144,    85,  1.05173E-08
                -48,    145,    85,  1.05173E-08
                -49,    146,    85,  1.05173E-08
                -50,    147,    85,  1.05173E-08
                -51,    148,    85,  1.05173E-08
                -52,    149,    85,  1.05173E-08
                -53,    150,    85,  1.05173E-08
                -54,    151,    85,  1.05173E-08
                -55,    152,    85,  1.05173E-08
                -56,    153,    85,  1.05173E-08
                -57,    154,    85,  1.05173E-08
                -58,    155,    85,  1.05173E-08
                -59,    156,    85,  1.05173E-08
                -60,    157,    85,  1.05173E-08
GEN -61, 18, 1, 58, 1, 85, 0, .1713E-8,  1., 2.49 , 1.$                36    06/16/73.  NEW
                -61,     58,    85,  4.26537E-09
                -62,     59,    85,  4.26537E-09
                -63,     60,    85,  4.26537E-09
                -64,     61,    85,  4.26537E-09
                -65,     62,    85,  4.26537E-09
                -66,     63,    85,  4.26537E-09
                -67,     64,    85,  4.26537E-09
                -68,     65,    85,  4.26537E-09
                -69,     66,    85,  4.26537E-09
                -70,     67,    85,  4.26537E-09
                -71,     68,    85,  4.26537E-09
                -72,     69,    85,  4.26537E-09
                -73,     70,    85,  4.26537E-09
                -74,     71,    85,  4.26537E-09
                -75,     72,    85,  4.26537E-09
                -76,     73,    85,  4.26537E-09
                -77,     74,    85,  4.26537E-09
                -78,     75,    85,  4.26537E-09
-79,176, 85, .1713E-8*71.$                                             37    06/16/73.  NEW
-80,137, 85, .1713E-8*71.$                                             38    06/16/73.  NEW
-81, 79, 76, .1713E-8*.1715C*339.$                                     39    06/16/73.  NEW
-82, 79, 77, .1713E-8*.3700C*339.$                                     40    06/16/73.  NEW
-300, 76, 77, .1713E-8*.1929*72.3                                      41    06/16/73.  NEW
GEN -83, 18, 1, 58, 1, 79, 0, .1713E-8, .03735, 339., 1.$              42    06/16/73.  NEW
                -83,     58,    79,  4.26820E-09
                -84,     59,    79,  4.26820E-09
                -85,     60,    79,  4.26820E-09
                -86,     61,    79,  4.26820E-09
                -87,     62,    79,  4.26820E-09
                -88,     63,    79,  4.26820E-09
                -89,     64,    79,  4.26820E-09
                -90,     65,    79,  4.26820E-09
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                        -91,    66,    79,  4.26821E-09
                        -92,    67,    79,  4.26821E-09
                        -93,    68,    79,  4.26821E-09
                        -94,    69,    79,  4.26821E-09
                        -95,    70,    79,  4.26821E-09
                        -96,    71,    79,  4.26821E-09
                        -97,    72,    79,  4.26821E-09
                        -98,    73,    79,  4.26821E-09
                        -99,    74,    79,  4.26821E-09
                       -100,    75,    79,  4.26821E-09
GEN -101, 18, 1, 40, 1, 79, 0, .1713E-8, .015100, 339., 1.3                  43    06/16/73.  NEW
                       -101,    40,    79,  1.05108E-08
                       -102,    41,    79,  1.05108E-08
                       -103,    42,    79,  1.05108E-08
                       -104,    43,    79,  1.05108E-08
                       -105,    44,    79,  1.05108E-08
                       -106,    45,    79,  1.05108E-08
                       -107,    46,    79,  1.05108E-08
                       -108,    47,    79,  1.05108E-08
                       -109,    48,    79,  1.05108E-08
                       -110,    49,    79,  1.05108E-08
                       -111,    50,    79,  1.05108E-08
                       -112,    51,    79,  1.05108E-08
                       -113,    52,    79,  1.05108E-08
                       -114,    53,    79,  1.05108E-08
                       -115,    54,    79,  1.05108E-08
                       -116,    55,    79,  1.05108E-08
                       -117,    56,    79,  1.05108E-08
                       -118,    57,    79,  1.05108E-08
-119, 37, 80, .1713E-8*.17470E*412.3                                         44    06/16/73.  NEW
-120, 38, 80, .1713E-8*.33900*412.3                                          45    06/16/73.  NEW
GEN -121, 18, 1, 1, 1, 80, 0, .1713E-8, .026370, 412., 1.8                   46    06/16/73.  NEW
                       -121,     1,    80,  1.90342E-08
                       -122,     2,    80,  1.90342E-08
                       -123,     3,    80,  1.90342E-08
                       -124,     4,    80,  1.90342E-08
                       -125,     5,    80,  1.90342E-08
                       -126,     6,    80,  1.90342E-08
                       -127,     7,    80,  1.90342E-08
                       -128,     8,    80,  1.90342E-08
                       -129,     9,    80,  1.90342E-08
                       -130,    10,    80,  1.90342E-08
                       -131,    11,    80,  1.90342E-08
                       -132,    12,    80,  1.90342E-08
                       -133,    13,    80,  1.90342E-08
                       -134,    14,    80,  1.90342E-08
                       -135,    15,    80,  1.90342E-08
                       -136,    16,    80,  1.90342E-08
                       -137,    17,    80,  1.90342E-08
                       -138,    18,    80,  1.90342E-08
END                                                                          47    06/16/73.  NEW
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ACTUAL CONDUCTOR NUMBERS

REL. COND. NO.		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1 -	20	1	3	5	195	214	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191
21 -	40	192	193	194	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212
41 -	60	213	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
61 -	80	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
81 -	100	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
101 -	120	300	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101
121 -	140	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121
141 -	157	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138			

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BCD 3CONSTANTS DATA                                                         48   06/16/73.  NEW
NDSTOP=700                                                                  49   06/16/73.  NEW
DTIMEI=.05                                                                  50   06/16/73.  NEW
OUTPUT=.5                                                                   51   06/16/73.  NEW
TIMEND=10.                                                                  52   06/16/73.  NEW
DPLXCA=.01                                                                  53   06/16/73.  NEW
APLXCA=.01                                                                  54   06/16/73.  NEW
NLOOP=100                                                                   55   06/16/73.  NEW
TIMEO=0.                                                                    56   06/16/73.  NEW
1=.07   $  OSR SOLAR ABSORPTIVITY                                           57   06/16/73.  NEW
2=.7    $  OSR EMISSIVITY                                                   58   06/16/73.  NEW
3=.2    $ EXTERNAL COVER SOLAR ABSORPTIVITY                                 59   06/16/73.  NEW
4=.70   $ EXTERNAL COVER EMISSIVITY                                         60   06/16/73.  NEW
5=0.$ 0. FOR INITIAL STDSTL, 1. FOR INITIAL FWDBCK                          61   06/16/73.  NEW
END                                                                         62   06/16/73.  NEW

REL. CONST. NO.                          ACTUAL CONSTANT NUMBERS
                 1    2    3    4    5    6    7    8    9   10    1    2    3    4    5    6    7    8    9   10
   1 -     5      1    2    3    4    5

BCD 3ARRAY DATA                                                             63   06/16/73.  NEW
1, SPACE, 50, END $ CONDUCTOR STORAGE                                       64   06/16/73.  NEW
100$SOLAR INCIDENT HEAT FLUX, BTU/HR SQ FT                                  65   06/16/73.  NEW
+43., 396., 294., 156., 40., 0., REPEAT, 3, +0., 150., 294., 396., 443.     66   06/16/73.  NEW
END $                                                                       67   06/16/73.  NEW
101 $ PLANETARY INCIDENT HEAT FLUX, BTU/HR SQ FT                            68   06/16/73.  NEW
5.3, 1.75, 0., REPEAT, 5, 1.75, 5.3, 17.85, 26.4, 33.9, 48., 52.1, 48.      69   06/16/73.  NEW
33.9, 26.4, 17.85                                                           70   06/16/73.  NEW
END                                                                         71   06/16/73.  NEW
102 $ TIME ARRAY FOR PROPELLANT USEAGE                                      72   06/16/73.  NEW
0., 100.$                                                                   73   06/16/73.  NEW
END $                                                                       74   06/16/73.  NEW
103 $ OXIDIZER WEIGHT                                                       75   06/16/73.  NEW
6550., 6550.$                                                               76   06/16/73.  NEW
END $                                                                       77   06/16/73.  NEW
104 $ FUEL WEIGHT                                                           78   06/16/73.  NEW
3275., 3275.$                                                               79   06/16/73.  NEW
END $                                                                       80   06/16/73.  NEW
 2,SPACE, 360, END $ NODE 18                                                81   06/16/73.  NEW
 4,SPACE, 360, END $ NODE 57                                                82   06/16/73.  NEW
 5,SPACE, 360, END $ NODE 75                                                83   06/16/73.  NEW
 6,SPACE, 360, END $ NODE  9                                                84   06/16/73.  NEW
 8,SPACE, 360, END $ NODE 48                                                85   06/16/73.  NEW
 9,SPACE, 360, END $ NODE 66                                                86   06/16/73.  NEW
10,SPACE, 360, END $ NODE  5                                                87   06/16/73.  NEW
12,SPACE, 360, END $ NODE 44                                                88   06/16/73.  NEW
13,SPACE, 360, END $ NODE 62                                                89   06/16/73.  NEW
14,SPACE, 360, END $ NODE 14                                                90   06/16/73.  NEW
16,SPACE, 360, END $ NODE 53                                                91   06/16/73.  NEW
17,SPACE, 360, END $ NODE 71                                                92   06/16/73.  NEW
18,SPACE, 360, END $ NODE 38                                                93   06/16/73.  NEW
19,SPACE, 360, END $ NODE 39                                                94   06/16/73.  NEW
20,SPACE, 360, END $ NODE 77                                                95   06/16/73.  NEW
21,SPACE, 360, END $ NODE 78                                                96   06/16/73.  NEW
22,SPACE, 360, END $ NODE 37                                                97   06/16/73.  NEW
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      23,SPACE, 360, END $ NODE 76                                   98    06/16/73.  NEW
      24,SPACE, 360, END $ NODE 31                                   99    06/16/73.  NEW
      25,SPACE, 360, END $ NODE 52                                  100    06/16/73.  NEW
      37,SPACE, 360, END $ TIMEN                                    101    06/16/73.  NEW
      41, SPACE, 360, END $ NODE 119                                102    06/16/73.  NEW
      42, SPACE, 360, END $ NODE 157                                103    06/16/73.  NEW
      43, SPACE, 360, END $ NODE 103                                104    06/16/73.  NEW
      44, SPACE, 360, END $ NODE 143                                105    06/16/73.  NEW
      45, SPACE, 360, END $ NODE 105                                106    06/16/73.  NEW
      46, SPACE, 360, END $ NODE 144                                107    06/16/73.  NEW
      47, SPACE, 360, END $ NODE 114                                108    06/16/73.  NEW
      48, SPACE, 360, END $ NODE 153                                109    06/16/73.  NEW
      50, SPACE, 360, END $ NODE 133                                110    06/16/73.  NEW
      52, SPACE, 360, END $ NODE 137                                111    06/16/73.  NEW
      53, SPACE, 360, END $ NODE 176                                112    06/16/73.  NEW
      59, SPACE, 360, END $ NODE 79                                 113    06/16/73.  NEW
      50, SPACE, 360, END $ NODE 80                                 114    06/16/73.  NEW
      51, SPACE, 360, END $ NODE 80 CAPACITY                        115    06/16/73.  NEW
      52, SPACE, 360, END $ NODE 81 CAPACITY                        116    06/16/73.  NEW
      53, SPACE, 360, END $ NODE 82 CAPACITY                        117    06/16/73.  NEW
C  PLOT TITLES                                                      118    06/16/73.  NEW
      28 $ PLOT 1                                                   119    06/16/73.  NEW
      300 9 TEMPERATURE OF NODES  5, 3, 14, 18                      120    06/16/73.  NEW
      300 3                                                         121    06/16/73.  NEW
      END                                                           122    06/16/73.  NEW
      30 $ PLOT 3                                                   123    06/16/73.  NEW
      300 9 TEMPERATURE OF NODES 44, 43, 53, 57                     124    06/16/73.  NEW
      300 3                                                         125    06/16/73.  NEW
      END                                                           126    06/16/73.  NEW
      31 $ PLOT 4                                                   127    06/16/73.  NEW
      300 9 TEMPERATURE OF NODES 62, 65, 71, 75                     128    06/16/73.  NEW
      300 3                                                         129    06/16/73.  NEW
      END                                                           130    06/16/73.  NEW
      32 $ PLOT 5                                                   131    06/16/73.  NEW
      300 9 TEMPERATURE OF NODES 38, 33, 77, 78                     132    06/16/73.  NEW
      300 3                                                         133    06/16/73.  NEW
      END                                                           134    06/16/73.  NEW
      33 $ PLOT 6                                                   135    06/16/73.  NEW
      300 9 TEMPERATURE OF NODES 37, 76                             136    06/16/73.  NEW
      300 3                                                         137    06/16/73.  NEW
      END                                                           138    06/16/73.  NEW
      34 $ PLOT 7                                                   139    06/16/73.  NEW
      300 9 TEMPERATURE OF NODES 81, 82                             140    06/16/73.  NEW
      300 3                                                         141    06/16/73.  NEW
      END                                                           142    06/16/73.  NEW
      55 $ PLOT 11                                                  143    06/16/73.  NEW
      300 9 TEMPERATURE OF NODES 144, 143, 153, 157                 144    06/16/73.  NEW
      300 3                                                         145    06/16/73.  NEW
      END                                                           146    06/16/73.  NEW
      57 $ PLOT 13                                                  147    06/16/73.  NEW
      300 9 TEMPERATURE OF NODE 139                                 148    06/16/73.  NEW
      300 3                                                         149    06/16/73.  NEW
      END                                                           150    06/16/73.  NEW
      58 $ PLOT 14                                                  151    06/16/73.  NEW
      300 9 TEMPERATURE OF NODES 137, 175                           152    06/16/73.  NEW
      300 3                                                         153    06/16/73.  NEW
      END                                                           154    06/16/73.  NEW
      38 $ X AXIS                                                   155    06/16/73.  NEW
      300 9 TIME, HOURS                                             156    06/16/73.  NEW
      300 3                                                         157    06/16/73.  NEW
      END                                                           158    06/16/73.  NEW
      33 $ Y AXIS                                                   159    06/16/73.  NEW
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300 9 TEMPERATURE, DEGF                                    160   06/16/73.  NEW
300 3                                                      161   06/16/73.  NEW
END                                                        162   06/16/73.  NEW
54 *                                                       163   06/16/73.  NEW
300 9 TEMPERATURE OF NODES 79, 83                          164   06/16/73.  NEW
300 3                                                      165   06/16/73.  NEW
END                                                        166   06/16/73.  NEW
55 *                                                       167   06/16/73.  NEW
300 9 CAPACITY OF NODES 80, 81, 82                         168   06/16/73.  NEW
300 3                                                      169   06/16/73.  NEW
END                                                        170   06/16/73.  NEW
56 *                                                       171   06/16/73.  NEW
300 9 CAPACITY, BTU/DEGF                                   172   06/16/73.  NEW
300 3                                                      173   06/16/73.  NEW
END                                                        174   06/16/73.  NEW
END                                                        175   06/16/73.  NEW
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RELATIVE ARRAY NO.	ACTUAL ARRAY NO.	STARTING LOCATION	NUMBER OF ELEMENTS
1	1	1	51
2	100	52	19
3	101	71	19
4	102	90	3
5	103	93	3
6	104	96	3
7	2	99	361
8	4	461	361
9	5	821	361
10	6	1182	361
11	8	1543	361
12	9	1904	361
13	10	2265	361
14	12	2626	361
15	13	2987	361
16	14	3349	361
17	16	3709	361
18	17	4071	361
19	18	4431	361
20	19	4792	361
21	20	5153	361
22	21	5514	361
23	22	5975	361
24	23	6236	361
25	24	6597	361
26	25	6953	361
27	37	7319	361
28	41	7681	361
29	42	8041	361
30	43	8402	361
31	44	8763	361
32	45	9124	361
33	46	9485	361
34	47	9845	361
35	48	10207	361
36	50	10563	361
37	52	10929	361
38	53	11290	361
39	59	11651	361
40	60	12012	361
41	61	12373	351
42	62	12734	361
43	63	13095	361
44	28	13455	13

45	30	13469	13
46	31	13482	13
47	32	13495	13
48	33	13508	13
49	34	13521	13
50	55	13534	13
51	57	13547	13
52	58	13560	13
53	38	13573	13
54	39	13586	13
55	64	13599	13
56	65	13612	13
57	66	13625	13

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      300 BEXECUTION                                                                176   06/16/73.  NEW
          JTEST=0                                                                   177   06/16/73.  NEW
          DO 4 I=1,18                                                               178   06/16/73.  NEW
          A1+I= 324+I-1                                                             179   06/16/73.  NEW
    4     A1+18+I=343+I-1                                                           180   06/16/73.  NEW
          A1+37=342                                                                 181   06/16/73.  NEW
          A1+38=379                                                                 182   06/16/73.  NEW
          A1+39=380                                                                 183   06/16/73.  NEW
    1     DO 5 I=1,18                                                               184   06/16/73.  NEW
          324+I-1=A1+I*R4                                                           185   06/16/73.  NEW
          343+I-1=A1+18+I*R4                                                        186   06/16/73.  NEW
    5     361+I-1=361+I-1 * R2                                                      187   06/16/73.  NEW
          342=A1+37*R4                                                              188   06/16/73.  NEW
          379=A1+38*R4                                                              189   06/16/73.  NEW
          380=A1+39*R4                                                              190   06/16/73.  NEW
          OUTPUT=0.                                                                 191   06/16/73.  NEW
          TIMEND=0.                                                                 192   06/16/73.  NEW
          NLOOP=500                                                                 193   06/16/73.  NEW
          BALENG=.5                                                                 194   06/16/73.  NEW
          R5=0.                                                                     195   06/16/73.  NEW
          STOSTL                                                                    196   06/16/73.  NEW
          OUTPUT=.5                                                                 197   06/16/73.  NEW
          TIMEND=100.                                                               198   06/16/73.  NEW
          BALENG=0.                                                                 199   06/16/73.  NEW
          NLOOP=100                                                                 200   06/16/73.  NEW
          TIMEO=0.                                                                  201   06/16/73.  NEW
          DTIMET=.05                                                                202   06/16/73.  NEW
          R5=1.                                                                     203   06/16/73.  NEW
          DO 15 I=1,18                                                              204   06/16/73.  NEW
          A1J+I=0.                                                                  205   06/16/73.  NEW
   15     A1J1+I=0.                                                                 206   06/16/73.  NEW
          FWDBCK                                                                    207   06/16/73.  NEW
          DRPELT                                                                    208   06/16/73.  NEW
          PLOTX2(-1, 0., 168., -49., 193., 44, A38+1, A39+1, A23+1, -JTEST, A37+1,  209   06/16/73.  NEW
     .          A10+1)$                                                             210   06/16/73.  NEW
          PLOTX2( 0, 0., 168., -49., 193., 44, A38+1, A39+1, A28+1, -JTEST, A37+1,  211   06/16/73.  NEW
     .          A 6+1)$                                                             212   06/16/73.  NEW
          PLOTX2( 0, 0., 168., -49., 193., 44, A38+1, A39+1, A23+1, -JTEST, A37+1,  213   06/16/73.  NEW
     .          A14+1)$                                                             214   06/16/73.  NEW
          PLOTX2( 0, 0., 168., -49., 193., 44, A38+1, A39+1, A23+1, -JTEST, A37+1,  215   06/16/73.  NEW
     .          A 2+1)$                                                             216   06/16/73.  NEW
          PLOTX2(-1, 0., 168., -49., 193., 44, A38+1, A39+1, A33+1, -JTEST, A37+1,  217   06/16/73.  NEW
     .          A12+1)$                                                             218   06/16/73.  NEW
          PLOTX2( 0, 0., 168., -49., 193., 44, A38+1, A39+1, A33+1, -JTEST, A37+1,  219   06/16/73.  NEW
     .          A 8+1)$                                                             220   06/16/73.  NEW
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      PLOTX2( 0, 0., 168., -49., 193., 44, A38+1, A39+1, A30+1, -JTEST, A37+1,     06/16/73. NEW
     . A16+1)$                                                                    06/16/73. NEW
      PLOTX2( 0, 0., 168., -49., 193., 44, A38+1, A39+1, A30+1, -JTEST, A37+1,     06/16/73. NEW
     . A 4+1)$                                                                    06/16/73. NEW
      PLOTX2(-1, 0., 168., -49., 193., 44, A38+1, A39+1, A31+1, -JTEST, A37+1,     06/16/73. NEW
     . A13+1)$                                                                    06/16/73. NEW
      PLOTX2( 0, 0., 168., -49., 193., 44, A38+1, A39+1, A31+1, -JTEST, A37+1,     06/16/73. NEW
     . A 9+1)$                                                                    06/16/73. NEW
      PLOTX2( 0, 0., 168., -49., 193., 44, A38+1, A39+1, A31+1, -JTEST, A37+1,     06/16/73. NEW
     . A17+1)$                                                                    06/16/73. NEW
      PLOTX2( 0, 0., 168., -49., 193., 44, A38+1, A39+1, A31+1, -JTEST, A37+1,     06/16/73. NEW
     . A 5+1)$                                                                    06/16/73. NEW
      PLOTX2(-1, 0., 168.,   0.,  99., 44, A38+1, A39+1, A32+1, -JTEST, A37+1,     06/16/73. NEW
     . A18+1)$                                                                    06/16/73. NEW
      PLOTX2( 0, 0., 168.,   0.,  99., 44, A38+1, A39+1, A32+1, -JTEST, A37+1,     06/16/73. NEW
     . A19+1)$                                                                    06/16/73. NEW
      PLOTX2( 0, 0., 168.,   0.,  99., 44, A38+1, A39+1, A32+1, -JTEST, A37+1,     06/16/73. NEW
     . A20+1)$                                                                    06/16/73. NEW
      PLOTX2( 0, 0., 168.,   0.,  99., 44, A38+1, A39+1, A32+1, -JTEST, A37+1,     06/16/73. NEW
     . A21+1)$                                                                    06/16/73. NEW
      PLOTX2(-1, 0., 168.,   0.,  99., 44, A38+1, A39+1, A33+1, -JTEST, A37+1,     06/16/73. NEW
     . A22+1)$                                                                    06/16/73. NEW
      PLOTX2( 0, 0., 168.,   0.,  99., 44, A38+1, A39+1, A33+1, -JTEST, A37+1,     06/16/73. NEW
     . A23+1)$                                                                    06/16/73. NEW
      PLOTX2(-1, 0., 168.,   0.,  99., 44, A38+1, A39+1, A34+1, -JTEST, A37+1,     06/16/73. NEW
     . A24+1)$                                                                    06/16/73. NEW
      PLOTX2( 0, 0., 168.,   0.,  99., 44, A38+1, A39+1, A34+1, -JTEST, A37+1,     06/16/73. NEW
     . A25+1)$                                                                    06/16/73. NEW
      PLOTX2(-1, 0., 168., -199., 293., 44, A38+1, A39+1, A55+1, -JTEST, A37+1,    06/16/73. NEW
     . A46+1) $                                                                   06/16/73. NEW
      PLOTX2( 0, 0., 168., -199., 293., 44, A38+1, A39+1, A55+1, -JTEST, A37+1,    06/16/73. NEW
     . A44+1) $                                                                   06/16/73. NEW
      PLOTX2( 0, 0., 168., -199., 293., 44, A38+1, A39+1, A55+1, -JTEST, A37+1,    06/16/73. NEW
     . A48+1) $                                                                   06/16/73. NEW
      PLOTX2( 0, 0., 168., -199., 293., 44, A38+1, A39+1, A55+1, -JTEST, A37+1,    06/16/73. NEW
     . A42+1)$                                                                    06/16/73. NEW
      PLOTX2(-1, 0., 168., -199., 293., 44, A38+1, A39+1, A57+1, -JTEST, A37+1,    06/16/73. NEW
     . A50+1) $                                                                   06/16/73. NEW
      PLOTX2(-1, 0., 168., -249., 243., 44, A38+1, A39+1, A58+1, -JTEST, A37+1,    06/16/73. NEW
     . A52+1) $                                                                   06/16/73. NEW
      PLOTX2( 0, 0., 168., -249., 243., 44, A38+1, A39+1, A58+1, -JTEST, A37+1,    06/16/73. NEW
     . A53+1) $                                                                   06/16/73. NEW
      PLOTX2(-1, 0., 168., 1.,    99., 44, A38+1, A39+1, A54+1, -JTEST, A37+1,     06/16/73. NEW
     . A59+1)$                                                                    06/16/73. NEW
      PLOTX2( 0, 0., 168., 1.,    99., 44, A38+1, A39+1, A54+1, -JTEST, A37+1,     06/16/73. NEW
     . A60+1)$                                                                    06/16/73. NEW
      PLOTX2(-1, 0., 168., 0., 9.9E3, 44, A38+1, A56+1, A55+1, -JTEST, A37+1,      06/16/73. NEW
     . A61+1)$                                                                    06/16/73. NEW
      PLOTX2( 0, 0., 168., 0., 9.9E3, 44, A38+1, A56+1, A55+1, -JTEST, A37+1,      06/16/73. NEW
     . A62+1)$                                                                    06/16/73. NEW
      PLOTX2( 0, 0., 168., 0., 9.9E3, 44, A38+1, A56+1, A55+1, -JTEST, A37+1,      06/16/73. NEW
     . A63+1)$                                                                    06/16/73. NEW
      PLTND                                                                       06/16/73. NEW
      END                                                                         06/16/73. NEW
      3CD 3VARIABLES 1                                                            06/16/73. NEW
      IF(P5.LT..5)GO TO 5                                                         06/16/73. NEW
C     INSERT CONSUMABLES CAPACITY ADJUSTMENT                                      06/16/73. NEW
 5    DO 10 I=1, 18                                                               06/16/73. NEW
      D101+I-1=(A100+I*R3+A101+I*R4)*11.12                                        06/16/73. NEW
      D139=D139 + (A100+I * R3 + A101+I * R4)*8.70                                06/16/73. NEW
      D140+I-1 = (A100+I * R3 + A101+I * R4)*5.14                                 06/16/73. NEW
 10   D58+I-1 = (A100+I * R1 + A101+I * R2)*2.43                                  06/16/73. NEW
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Q176=Q137=13.*72.* R4                                          283   06/16/73.  NEW
Q79=2752. $ AVIONICS HEAT DISSIPATION                          284   06/16/73.  NEW
D11MDA(TIMEN, A102, A103, .37, C32)                            285   06/16/73.  NEW
D11MDA(TIMEN, A102, A104, .7, C81)                             286   06/16/73.  NEW
END                                                            287   06/16/73.  NEW
BCD 3VARIABLES 2                                               288   06/16/73.  NEW
END                                                            289   06/16/73.  NEW
BCD 3OUTPUT CALLS                                              290   06/16/73.  NEW
TPRINT                                                         291   06/16/73.  NEW
JTEST=JTEST+1                                                  292   06/16/73.  NEW
A 2 + JTEST = T18                                              293   06/16/73.  NEW
A 4 + JTEST = T57                                              294   06/16/73.  NEW
A 5 + JTEST = T75                                              295   06/16/73.  NEW
A 6 + JTEST = T 9                                              296   06/16/73.  NEW
A 8 + JTEST = T48                                              297   06/16/73.  NEW
A 9 + JTEST = T66                                              298   06/16/73.  NEW
A10 + JTEST = T 5                                              299   06/16/73.  NEW
A12 + JTEST = T44                                              300   06/16/73.  NEW
A13 + JTEST = T52                                              301   06/16/73.  NEW
A14 + JTEST = T14                                              302   06/16/73.  NEW
A15 + JTEST = T53                                              303   06/16/73.  NEW
A17 + JTEST = T71                                              304   06/16/73.  NEW
A18 + JTEST = T38                                              305   06/16/73.  NEW
A19 + JTEST = T39                                              306   06/16/73.  NEW
A20 + JTEST = T77                                              307   06/16/73.  NEW
A21 + JTEST = T78                                              308   06/16/73.  NEW
A22 + JTEST = T37                                              309   06/16/73.  NEW
A23 + JTEST = T76                                              310   06/16/73.  NEW
A24 + JTEST = T81                                              311   06/16/73.  NEW
A25 + JTEST = T82                                              312   06/16/73.  NEW
A37 + JTEST = TIMEN                                            313   06/16/73.  NEW
A41 + JTEST = T118                                             314   06/16/73.  NEW
A42 + JTEST = T157                                             315   06/16/73.  NEW
A43 + JTEST = T109                                             316   06/16/73.  NEW
A44 + JTEST = T148                                             317   06/16/73.  NEW
A45 + JTEST = T105                                             318   06/16/73.  NEW
A46 + JTEST = T144                                             319   06/16/73.  NEW
A47 + JTEST = T114                                             320   06/16/73.  NEW
A48 + JTEST = T153                                             321   06/16/73.  NEW
A50 + JTEST = T139                                             322   06/16/73.  NEW
A52 + JTEST = T137                                             323   06/16/73.  NEW
A53 + JTEST = T176                                             324   06/16/73.  NEW
A59 + JTEST = T79                                              325   06/16/73.  NEW
A60 + JTEST = T80                                              326   06/16/73.  NEW
A61 + JTEST = C80                                              327   06/16/73.  NEW
A62 + JTEST = C81                                              328   06/16/73.  NEW
A63 + JTEST = C82                                              329   06/16/73.  NEW
IF(T81.LT.-62.5.OR.T82.LT.11.3)TIMEND=TIMEN                    330   06/16/73.  NEW
END                                                            331   06/16/73.  NEW
BCD 3END OF DATA                                               332   06/16/73.  NEW

INITIAL CONDITIONS HAVE BEEN STORED ON TAPE 22, SO RESTART OF INITIAL CONDITIONS CAN BE PERFORMED.
 THE RESTART NAME IS ST0000
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Table C-3 MITAS Input for Geosynchronous Tug Thermal Model Without MLI

NOT RECALL

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BCD 3THERMAL LPCS                                           1   08/30/73.  NEW
BCD 9 CONFIG 2,NO MLI,NO RAD,GEOSYNCH MISSION               2   08/30/73.  NEW
END                                                         3   08/30/73.  NEW
BCD 3NODE DATA                                              4   08/30/73.  NEW
GEN 1, 18, 1, 70., 1.81, 1., 1., 1.$                        5   08/30/73.  NEW
                    1,  7.00000E+01,  1.81000E+00
                    2,  7.00000E+01,  1.81000E+00
                    3,  7.00000E+01,  1.81000E+00
                    4,  7.00000E+01,  1.81000E+00
                    5,  7.00000E+01,  1.81000E+00
                    6,  7.00000E+01,  1.81000E+00
                    7,  7.00000E+01,  1.81000E+00
                    8,  7.00000E+01,  1.81000E+00
                    9,  7.00000E+01,  1.81000E+00
                   10,  7.00000E+01,  1.81000E+00
                   11,  7.00000E+01,  1.81000E+00
                   12,  7.00000E+01,  1.81000E+00
                   13,  7.00000E+01,  1.81000E+00
                   14,  7.00000E+01,  1.81000E+00
                   15,  7.00000E+01,  1.81000E+00
                   16,  7.00000E+01,  1.81000E+00
                   17,  7.00000E+01,  1.81000E+00
                   18,  7.00000E+01,  1.81000E+00
39, 70., 18.5$                                              6   08/30/73.  NEW
GEN 40, 18, 1, 70., 1.112, 1., 1., 1.$                      7   08/30/73.  NEW
                   40,  7.00000E+01,  1.11200E+00
                   41,  7.00000E+01,  1.11200E+00
                   42,  7.00000E+01,  1.11200E+00
                   43,  7.00000E+01,  1.11200E+00
                   44,  7.00000E+01,  1.11200E+00
                   45,  7.00000E+01,  1.11200E+00
                   46,  7.00000E+01,  1.11200E+00
                   47,  7.00000E+01,  1.11200E+00
                   48,  7.00000E+01,  1.11200E+00
                   49,  7.00000E+01,  1.11200E+00
                   50,  7.00000E+01,  1.11200E+00
                   51,  7.00000E+01,  1.11200E+00
                   52,  7.00000E+01,  1.11200E+00
                   53,  7.00000E+01,  1.11200E+00
                   54,  7.00000E+01,  1.11200E+00
                   55,  7.00000E+01,  1.11200E+00
                   56,  7.00000E+01,  1.11200E+00
                   57,  7.00000E+01,  1.11200E+00
GEN 58, 18, 1, 70., .451, 1., 1., 1.$                       8   08/30/73.  NEW
                   58,  7.00000E+01,  4.51000E-01
                   59,  7.00000E+01,  4.51000E-01
                   60,  7.00000E+01,  4.51000E-01
                   61,  7.00000E+01,  4.51000E-01
                   62,  7.00000E+01,  4.51000E-01
                   63,  7.00000E+01,  4.51000E-01
                   64,  7.00000E+01,  4.51000E-01
                   65,  7.00000E+01,  4.51000E-01
                   66,  7.00000E+01,  4.51000E-01
                   67,  7.00000E+01,  4.51000E-01
                   68,  7.00000E+01,  4.51000E-01
                   69,  7.00000E+01,  4.51000E-01
                   70,  7.00000E+01,  4.51000E-01
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                                   71,  7.00000E+01,  4.51000E-01
                                   72,  7.00000E+01,  4.51000E-01
                                   73,  7.00000E+01,  4.51000E-01
                                   74,  7.00000E+01,  4.51000E-01
                                   75,  7.00000E+01,  4.51000E-01
                    73, 70., 12.02$                                                                    9     08/30/73.  NEW
                    79, 70., 70.6$                                                                    10     08/30/73.  NEW
                    80, 70., 600.$                                                                    11     08/30/73.  NEW
                    81, 70., 1.$                                                                      12     08/30/73.  NEW
                    82, 70., 1.$                                                                      13     08/30/73.  NEW
                    36, 70., 8.34$                                                                    14     08/30/73.  NEW
                    77, 70., 16.695                                                                   15     08/30/73.  NEW
                    37, 70., -1.$                                                                     16     08/30/73.  NEW
                    76, 70., -1.$                                                                     17     08/30/73.  NEW
                    137, 70., -1.$                                                                    18     08/30/73.  NEW
                    176, 70., -1.$                                                                    19     08/30/73.  NEW
                    -65, -460., 1.$                                                                   20     08/30/73.  NEW
                    END                                                                               21     08/30/73.  NEW

REL. NODE NO.                                                 ACTUAL NODE NUMBERS
                    1     2     3     4     5     6     7     8     9    10     1     2     3     4     5     6     7     8     9    10
  1 -   20          1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    39    40
 21 -   40         41    42    43    44    45    46    47    48    49    50    51    52    53    54    55    56    57    58    59    60
 41 -   60         61    62    63    64    65    66    67    68    69    70    71    72    73    74    75    73    79    80    81    82
 61 -   67         36    77    37    76   137   176    85


                    ROD 3CONDUCTOR DATA                                                               22     08/30/73.  NEW
                    1, 77,82, 78, 32, 42.1$                                                           23     08/30/73.  NEW
                    3, 76,81, 36,81, 42.1$                                                            24     08/30/73.  NEW
                    5, 39, 81, 46.6$                                                                  25     08/30/73.  NEW
                    214, 76, 176, 37, 137, 7.E-4*72./.0633$                                           26     08/30/73.  NEW
                    GEN -24, 18, 1, 1, 1, 85, 0, .1713E-8, 1., 6.970, 1.$                             27     08/30/73.  NEW
                                  -24,     1,    85,  1.70786E-08
                                  -25,     2,    85,  1.70786E-08
                                  -26,     3,    85,  1.70786E-08
                                  -27,     4,    85,  1.70786E-08
                                  -28,     5,    85,  1.70786E-08
                                  -29,     6,    85,  1.70786E-08
                                  -30,     7,    85,  1.70786E-08
                                  -31,     8,    85,  1.70786E-08
                                  -32,     9,    85,  1.70786E-08
                                  -33,    10,    85,  1.70786E-08
                                  -34,    11,    85,  1.70786E-08
                                  -35,    12,    85,  1.70786E-08
                                  -36,    13,    85,  1.70786E-08
                                  -37,    14,    85,  1.70786E-08
                                  -38,    15,    85,  1.70786E-08
                                  -39,    16,    85,  1.70786E-08
                                  -40,    17,    85,  1.70786E-08
                                  -41,    18,    85,  1.70786E-08
                    -42, 39, 85, .1713E-8*156.8$                                                      28     08/30/73.  NEW
                    GEN -43, 18, 1, 40, 1, 85, 0, .1713E-8, 1., 6.140, 1.$                            29     08/30/73.  NEW
                                  -43,    40,    85,  1.05178E-08
                                  -44,    41,    85,  1.05178E-08
                                  -45,    42,    85,  1.05178E-08
                                  -46,    43,    85,  1.05178E-08
                                  -47,    44,    85,  1.05178E-08
                                  -48,    45,    85,  1.05178E-08
                                  -49,    46,    85,  1.05178E-08
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             -50,     47,     85,   1.05173E-08
             -51,     48,     85,   1.05176E-08
             -52,     49,     85,   1.05176E-08
             -53,     50,     85,   1.05176E-08
             -54,     51,     85,   1.05178E-08
             -55,     52,     85,   1.05178E-08
             -56,     53,     85,   1.05176E-08
             -57,     54,     85,   1.05178E-08
             -58,     55,     85,   1.05178E-08
             -59,     56,     85,   1.05178E-08
             -60,     57,     85,   1.05178E-08
GEN -61, 15, 1, 58, 1, 85, 0, .1713E-8,  1., 2.43 , 1.3          30     03/30/73.   NEW
             -61,     58,     85,   4.26537E-09
             -62,     59,     85,   4.26537E-09
             -63,     60,     85,   4.26537E-09
             -64,     61,     85,   4.26537E-09
             -65,     62,     85,   4.26537E-09
             -66,     63,     85,   4.26537E-09
             -67,     64,     85,   4.26537E-09
             -68,     65,     85,   4.26537E-09
             -69,     66,     85,   4.26537E-09
             -70,     67,     85,   4.26537E-09
             -71,     68,     85,   4.26537E-09
             -72,     69,     85,   4.26537E-09
             -73,     70,     85,   4.26537E-09
             -74,     71,     85,   4.26537E-09
             -75,     72,     85,   4.26537E-09
             -76,     73,     85,   4.26537E-09
             -77,     74,     85,   4.26537E-09
             -78,     75,     85,   4.26537E-09
-79,176, 85, .1713E-8*71.3                                      31     03/30/73.   NEW
-80,137, 85, .1713E-8*71.7                                      32     03/30/73.   NEW
-81, 79, 75, .1713E-8*.17130*339.3                              33     03/30/73.   NEW
-82, 79, 77, .1713E-8*.37000*339.6                              34     03/30/73.   NEW
-300, 76, 77, .1713E-8*.1020*72.3                               35     03/30/73.   NEW
GEN -83, 18, 1, 58, 1, 79, 0, .1713E-8, .00735, 339., 1.8       36     03/30/73.   NEW
             -83,     58,     79,   4.26520E-09
             -84,     59,     79,   4.26520E-09
             -85,     60,     79,   4.26520E-09
             -86,     61,     79,   4.26520E-09
             -87,     62,     79,   4.26520E-09
             -88,     63,     79,   4.26520E-09
             -89,     64,     79,   4.26520E-09
             -90,     65,     79,   4.26520E-09
             -91,     66,     79,   4.26520E-09
             -92,     67,     79,   4.26520E-09
             -93,     68,     79,   4.26520E-09
             -94,     69,     79,   4.26520E-09
             -95,     70,     79,   4.26520E-09
             -96,     71,     79,   4.26520E-09
             -97,     72,     79,   4.26520E-09
             -98,     73,     79,   4.26520E-09
             -99,     74,     79,   4.26520E-09
            -100,     75,     79,   4.26520E-09
GEN -101, 15, 1, 40, 1, 79, 0, .1713E-8, .010100, 339., 1.3     37     03/30/73.   NEW
            -101,     40,     79,   1.05198E-08
            -102,     41,     79,   1.05196E-08
            -103,     42,     79,   1.05198E-08
            -104,     43,     79,   1.05198E-08
            -105,     44,     79,   1.05198E-08
            -106,     45,     79,   1.05196E-08
            -107,     46,     79,   1.05196E-08
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          -108;     47;     73;  1.05108E-08
          -109;     48;     73;  1.05108E-08
          -110,     49,     79,  1.05108E-08
          -111,     50,     79,  1.05108E-08
          -112,     51,     79,  1.05108E-08
          -113,     52,     79,  1.05108E-08
          -114,     53,     79,  1.05108E-08
          -115,     54,     79,  1.05108E-08
          -116,     55,     79,  1.05108E-08
          -117,     56,     79,  1.05108E-08
          -118,     57,     79,  1.05108E-08
-119, 37, 80, .1713E-8*.17470*412.8                                    38    08/30/73.  NEW
-120, 38, 80, .1713E-8*.33900*412.8                                    39    08/30/73.  NEW
GEN -121, 18, 1, 1, 1, 80, 0, .1713E-8, .026970, 412., 1.8             40    08/30/73.  NEW
          -121,      1,     80,  1.90342E-08
          -122,      2,     80,  1.90342E-08
          -123,      3,     80,  1.90342E-08
          -124,      4,     80,  1.90342E-08
          -125,      5,     80,  1.90342E-08
          -126,      6,     80,  1.90342E-08
          -127,      7,     80,  1.90342E-08
          -128,      8,     80,  1.90342E-08
          -129,      9,     80,  1.90342E-08
          -130,     10,     80,  1.90342E-08
          -131,     11,     80,  1.90342E-08
          -132,     12,     80,  1.90342E-08
          -133,     13,     80,  1.90342E-08
          -134,     14,     80,  1.90342E-08
          -135,     15,     80,  1.90342E-08
          -136,     16,     80,  1.90342E-08
          -137,     17,     80,  1.90342E-08
          -138,     18,     80,  1.90342E-08
END                                                                    41    08/30/73.  NEW

REL. COND. NO.                          ACTUAL CONDUCTOR NUMBERS
              1    2    3    4    5    6    7    8    9   10    1    2    3    4    5    6    7    8    9   10
  1 -   20    1    3    5  214   24   25   26   27   28   29   30   31   32   33   34   35   36   37   38   39
 21 -   40   40   41   42   43   44   45   46   47   48   49   50   51   52   53   54   55   56   57   58   59
 41 -   60   60   61   62   63   64   65   66   67   68   69   70   71   72   73   74   75   76   77   78   79
 61 -   80   80   81   82  300   83   84   85   86   87   88   89   90   91   92   93   94   95   96   97   98
 81 -  100   99  100  101  102  103  104  105  106  107  108  109  110  111  112  113  114  115  116  117  118
101 -  120  119  120  121  122  123  124  125  126  127  128  129  130  131  132  133  134  135  136  137  138

ADD 3CONSTANTS DATA                                                    42    08/30/73.  NEW
NOSTOR=700                                                             43    08/30/73.  NEW
DTIMEI=.05                                                             44    08/30/73.  NEW
OUTPUT=.5                                                              45    08/30/73.  NEW
TIMEND=100.                                                            46    08/30/73.  NEW
DRLXCA=.01                                                             47    08/30/73.  NEW
ARLXCA=.01                                                             48    08/30/73.  NEW
NLOOP=100                                                              49    08/30/73.  NEW
TIMEO=0.                                                               50    08/30/73.  NEW
1=.07   $  DSP SOLAR ABSORPTIVITY                                      51    08/30/73.  NEW
2=.7    $  DSP EMISSIVITY                                              52    08/30/73.  NEW
3=.2    $ EXTERNAL TANK  SOLAR ABSORPTIVITY                            53    08/30/73.  NEW
4=.29   $ EXTERNAL TANK  EMISSIVITY                                    54    08/30/73.  NEW
5=1.$ 0. FOR INITIAL STDSTL, 1. FOR INITIAL FWDBCK                     55    08/30/73.  NEW
6=.25 $ SKIRT AND END SOLAR ABSORPTIVITY                               56    08/30/73.  NEW
7=.035 $ SKIRT AND END EMISSIVITY                                      57    08/30/73.  NEW
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          END                                                          58    08/30/73.  NEW
REL. CONST. NO.                              ACTUAL CONSTANT NUMBERS
              1    2    3    4    5    6    7    8    9   10    1    2    3    4    5    6    7    8    9   10
  1 -    7     1    2    3    4    5    6    7

          BCD 3ARRAY DATA                                              59    08/30/73.  NEW
          100$SOLAR INCIDENT HEAT FLUX, BTU/HR SQ FT                   60    08/30/73.  NEW
          443., 396., 294., 156., 40., 0., REPEAT, 6, 40., 156., 294., 396., 443.   61    08/30/73.  NEW
          END $                                                        62    08/30/73.  NEW
          101 $ PLANETARY INCIDENT HEAT FLUX, BTU/HR SQ FT             63    08/30/73.  NEW
          6.3, 1.75, 0., REPEAT, 5, 1.75, 6.3, 17.85, 28.4, 39.9, 48., 52.1, 48.   64    08/30/73.  NEW
          39.9, 28.4, 17.85                                            65    08/30/73.  NEW
          END                                                          66    08/30/73.  NEW
          102 $ TIME ARRAY FOR PROPELLANT USEAGE                       67    08/30/73.  NEW
          0., 6.2, 6.201, 11.3, 11.301, 16.6, 16.601, 100.$            68    08/30/73.  NEW
          END $                                                        69    08/30/73.  NEW
          103 $ OXIDIZER WEIGHT                                        70    08/30/73.  NEW
          36667., 36667., 22351., 22351., 14751., 14751., 6551., 6551.$   71    08/30/73.  NEW
          END $                                                        72    08/30/73.  NEW
          104 $ FUEL WEIGHT                                            73    08/30/73.  NEW
          18333., 18333., 11175., 11175., 7375., 7375., 3275., 3275.$  74    08/30/73.  NEW
          END $                                                        75    08/30/73.  NEW
           2,SPACE, 360, END $ NODE 13                                 76    08/30/73.  NEW
           4,SPACE, 360, END $ NODE 57                                 77    08/30/73.  NEW
           5,SPACE, 360, END $ NODE 75                                 78    08/30/73.  NEW
           6,SPACE, 360, END $ NODE  9                                 79    08/30/73.  NEW
           8,SPACE, 360, END $ NODE 48                                 80    08/30/73.  NEW
           9,SPACE, 360, END $ NODE 66                                 81    08/30/73.  NEW
          10,SPACE, 360, END $ NODE  5                                 82    08/30/73.  NEW
          12,SPACE, 360, END $ NODE 44                                 83    08/30/73.  NEW
          13,SPACE, 360, END $ NODE 62                                 84    08/30/73.  NEW
          14,SPACE, 360, END $ NODE 14                                 85    08/30/73.  NEW
          16,SPACE, 360, END $ NODE 53                                 86    08/30/73.  NEW
          17,SPACE, 360, END $ NODE 71                                 87    08/30/73.  NEW
          18,SPACE, 360, END $ NODE 33                                 88    08/30/73.  NEW
          19,SPACE, 360, END $ NODE 39                                 89    08/30/73.  NEW
          20,SPACE, 360, END $ NODE 77                                 90    08/30/73.  NEW
          21,SPACE, 360, END $ NODE 73                                 91    08/30/73.  NEW
          22,SPACE, 360, END $ NODE 37                                 92    08/30/73.  NEW
          23,SPACE, 360, END $ NODE 76                                 93    08/30/73.  NEW
          24,SPACE, 360, END $ NODE 81                                 94    08/30/73.  NEW
          25,SPACE, 360, END $ NODE 82                                 95    08/30/73.  NEW
          37,SPACE, 360, END $ TIMEN                                   96    08/30/73.  NEW
          52, SPACE, 360, END $ NODE 137                               97    08/30/73.  NEW
          53, SPACE, 360, END $ NODE 176                               98    08/30/73.  NEW
          59, SPACE, 360, END $ NODE 79                                99    08/30/73.  NEW
          60, SPACE, 360, END $ NODE 80                               100    08/30/73.  NEW
          61, SPACE, 360, END $ NODE 80 CAPACITY                      101    08/30/73.  NEW
          62, SPACE, 360, END $ NODE 81 CAPACITY                      102    08/30/73.  NEW
          63, SPACE, 360, END $ NODE 82 CAPACITY                      103    08/30/73.  NEW
     C  PLOT TITLES                                                   104    08/30/73.  NEW
          28 $ PLOT 1                                                 105    08/30/73.  NEW
          BCD 9 TEMPERATURE OF NODES  5,  9, 14, 18                   106    08/30/73.  NEW
          BCD 3                                                       107    08/30/73.  NEW
          END                                                         108    08/30/73.  NEW
          30 $ PLOT 3                                                 109    08/30/73.  NEW
          BCD 9 TEMPERATURE OF NODES 44, 48, 53, 57                   110    08/30/73.  NEW
          BCD 3                                                       111    08/30/73.  NEW
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END                                                       112   08/30/73.   NEW
31 $ PLOT 4                                               113   08/30/73.   NEW
BCD 9 TEMPERATURE OF NODES 62, 66, 71, 75                 114   08/30/73.   NEW
BCD 3                                                     115   08/30/73.   NEW
END                                                       116   08/30/73.   NEW
32 $ PLOT 5                                               117   08/30/73.   NEW
BCD 9 TEMPERATURE OF NODES 35, 39, 77, 78                 118   08/30/73.   NEW
BCD 3                                                     119   08/30/73.   NEW
END                                                       120   08/30/73.   NEW
33 $ PLOT 6                                               121   08/30/73.   NEW
BCD 9 TEMPERATURE OF NODES 37, 76                         122   08/30/73.   NEW
BCD 3                                                     123   08/30/73.   NEW
END                                                       124   08/30/73.   NEW
34 $ PLOT 7                                               125   08/30/73.   NEW
BCD 9 TEMPERATURE OF NODES 81, 82                         126   08/30/73.   NEW
BCD 3                                                     127   08/30/73.   NEW
END                                                       128   08/30/73.   NEW
58 $ PLOT 14                                              129   08/30/73.   NEW
BCD 9 TEMPERATURE OF NODES 137, 176                       130   08/30/73.   NEW
BCD 3                                                     131   08/30/73.   NEW
END                                                       132   08/30/73.   NEW
35 $ X AXIS                                               133   08/30/73.   NEW
BCD 9 TIME, HOURS                                         134   08/30/73.   NEW
BCD 3                                                     135   08/30/73.   NEW
END                                                       136   08/30/73.   NEW
39 $ Y AXIS                                               137   08/30/73.   NEW
BCD 9 TEMPERATURE, DEGF                                   138   08/30/73.   NEW
BCD 3                                                     139   08/30/73.   NEW
END                                                       140   08/30/73.   NEW
64 $                                                      141   08/30/73.   NEW
BCD 9 TEMPERATURE OF NODES 79, 80                         142   08/30/73.   NEW
BCD 3                                                     143   08/30/73.   NEW
END                                                       144   08/30/73.   NEW
65 $                                                      145   08/30/73.   NEW
BCD 9 CAPACITY OF NODES 80, 81, 82                        146   08/30/73.   NEW
BCD 3                                                     147   08/30/73.   NEW
END                                                       148   08/30/73.   NEW
66 $                                                      149   08/30/73.   NEW
BCD 9 CAPACITY, BTU/DEGF                                  150   08/30/73.   NEW
BCD 3                                                     151   08/30/73.   NEW
END                                                       152   08/30/73.   NEW
END                                                       153   08/30/73.   NEW
```

RELATIVE ARRAY NO.	ACTUAL ARRAY NO.	STARTING LOCATION	NUMBER OF ELEMENTS
1	100	1	19
2	101	20	19
3	102	39	9
4	103	48	9
5	104	57	9
6	2	66	361
7	4	427	361
8	5	788	361
9	6	1149	361
10	8	1510	361
11	9	1871	361
12	10	2232	361
13	12	2593	361
14	13	2954	361
15	14	3315	361
16	16	3676	361
17	17	4037	361
18	18	4398	361

19	19	4759	361
20	20	5120	361
21	21	5481	361
22	22	5842	361
23	23	6203	361
24	24	6564	361
25	25	6925	361
26	37	7286	361
27	52	7647	361
28	53	8008	361
29	59	8369	361
30	60	8730	361
31	61	9091	361
32	62	9452	361
33	63	9813	361
34	29	10174	13
35	30	10187	13
36	31	10200	13
37	32	10213	13
38	33	10226	13
39	34	10239	13
40	58	10252	13
41	38	10265	13
42	39	10278	13
43	64	10291	13
44	65	10304	13
45	66	10317	13

```
      800 33EXECUTION                                                        154   08/30/73.  NEW
      JTEST=0                                                                155   08/30/73.  NEW
      DO 5 I=1,13                                                            156   08/30/73.  NEW
      G24+I-1=G24+I-1 * R4                                                   157   08/30/73.  NEW
      G43+I-1=G43+I-1 * R4                                                   158   08/30/73.  NEW
    5 G61+I-1=G61+I-1 * R2                                                   159   08/30/73.  NEW
      G42=G42 * R4                                                           160   08/30/73.  NEW
      G79=G79 * R7                                                           161   08/30/73.  NEW
      G80=G80 * R7                                                           162   08/30/73.  NEW
      ENDBCK                                                                 163   08/30/73.  NEW
      OPNPLT                                                                 164   08/30/73.  NEW
      PLOTX2(-1, 0.,  99., -120., 120., 44, A38+1, A39+1, A28+1, -JTEST, A37+1,  165   08/30/73.  NEW
     .      A10+1)$                                                          166   08/30/73.  NEW
      PLOTX2( 0, 0.,  99.,-120., 120., 44, A38+1, A39+1, A28+1, -JTEST, A37+1,   167   08/30/73.  NEW
     .      A 6+1)$                                                          168   08/30/73.  NEW
      PLOTX2( 0, 0.,  99.,-120., 120., 44, A38+1, A39+1, A28+1, -JTEST, A37+1,   169   08/30/73.  NEW
     .      A14+1)$                                                          170   08/30/73.  NEW
      PLOTX2( 0, 0.,  99.,-120., 120., 44, A38+1, A39+1, A28+1, -JTEST, A37+1,   171   08/30/73.  NEW
     .      A 2+1)$                                                          172   08/30/73.  NEW
      PLOTX2(-1, 0.,  99., -39., 119., 44, A38+1, A39+1, A30+1, -JTEST, A37+1,   173   08/30/73.  NEW
     .      A12+1)$                                                          174   08/30/73.  NEW
      PLOTX2( 0, 0.,  99., -39., 119., 44, A38+1, A39+1, A30+1, -JTEST, A37+1,   175   08/30/73.  NEW
     .      A 9+1)$                                                          176   08/30/73.  NEW
      PLOTX2( 0, 0.,  99., -39., 119., 44, A38+1, A39+1, A30+1, -JTEST, A37+1,   177   08/30/73.  NEW
     .      A16+1)$                                                          178   08/30/73.  NEW
      PLOTX2( 0, 0.,  99., -39., 119., 44, A38+1, A39+1, A30+1, -JTEST, A37+1,   179   08/30/73.  NEW
     .      A 4+1)$                                                          180   08/30/73.  NEW
      PLOTX2(-1, 0.,  99., -70.,  70., 44, A38+1, A39+1, A31+1, -JTEST, A37+1,   181   08/30/73.  NEW
     .      A13+1)$                                                          182   08/30/73.  NEW
      PLOTX2( 0, 0.,  99., -70.,  70., 44, A38+1, A39+1, A31+1, -JTEST, A37+1,   183   08/30/73.  NEW
     .      A 9+1)$                                                          184   08/30/73.  NEW
```

```
      PLOTX2( 0, 0.,  99., -70.,  70., 44, A38+1, A39+1, A31+1, -JTEST, A37+1,      08/30/73.  NEW
     .        A17+1)$                                                               08/30/73.  NEW
      PLOTX2( 0, 0.,  99., -70.,  70., 44, A38+1, A39+1, A31+1, -JTEST, A37+1,      08/30/73.  NEW
     .        A 5+1)$                                                               08/30/73.  NEW
      PLOTX2(-1, 0.,  99., -80.,  80., 44, A38+1, A39+1, A32+1, -JTEST, A37+1,      08/30/73.  NEW
     .        A18+1)$                                                               08/30/73.  NEW
      PLOTX2( 0, 0.,  99., -80.,  80., 44, A38+1, A39+1, A32+1, -JTEST, A37+1,      08/30/73.  NEW
     .        A19+1)$                                                               08/30/73.  NEW
      PLOTX2( 0, 0.,  99., -80.,  80., 44, A38+1, A39+1, A32+1, -JTEST, A37+1,      08/30/73.  NEW
     .        A20+1)$                                                               08/30/73.  NEW
      PLOTX2( 0, 0.,  99., -80.,  80., 44, A38+1, A39+1, A32+1, -JTEST, A37+1,      08/30/73.  NEW
     .        A21+1)$                                                               08/30/73.  NEW
      PLOTX2(-1, 0.,  99., -100.,  80., 44, A38+1, A39+1, A33+1, -JTEST, A37+1,     08/30/73.  NEW
     .        A22+1)$                                                               08/30/73.  NEW
      PLOTX2( 0, 0.,  99., -100.,  80., 44, A38+1, A39+1, A33+1, -JTEST, A37+1,     08/30/73.  NEW
     .        A23+1)$                                                               08/30/73.  NEW
      PLOTX2(-1, 0.,  99., -50.,  80., 44, A38+1, A39+1, A34+1, -JTEST, A37+1,      08/30/73.  NEW
     .        A24+1)$                                                               08/30/73.  NEW
      PLOTX2( 0, 0.,  99., -50.,  80., 44, A38+1, A39+1, A34+1, -JTEST, A37+1,      08/30/73.  NEW
     .        A25+1)$                                                               08/30/73.  NEW
      PLOTX2(-1, 0.,  99., -120.,  70., 44, A38+1, A39+1, A58+1, -JTEST, A37+1,     08/30/73.  NEW
     .        A52+1) $                                                              08/30/73.  NEW
      PLOTX2( 0, 0.,  99., -120.,  70., 44, A38+1, A39+1, A55+1, -JTEST, A37+1,     08/30/73.  NEW
     .        A53+1) $                                                              08/30/73.  NEW
      PLOTX2(-1, 0.,  99., -100.,  80., 44, A38+1, A39+1, A64+1, -JTEST, A37+1,     08/30/73.  NEW
     .        A59+1)$                                                               08/30/73.  NEW
      PLOTX2( 0, 0.,  99., -100.,  80., 44, A38+1, A39+1, A64+1, -JTEST, A37+1,     08/30/73.  NEW
     .        A60+1)$                                                               08/30/73.  NEW
      PLOTX2( 0, 0.,  99., 0., 1.49E4, 44, A38+1, A66+1, A65+1, -JTEST, A37+1,      08/30/73.  NEW
     .        A61+1)$                                                               08/30/73.  NEW
      PLOTX2(-1, 0.,  99., 0., 1.49E4, 44, A38+1, A66+1, A65+1, -JTEST, A37+1,      08/30/73.  NEW
     .        A62+1)$                                                               08/30/73.  NEW
      PLOTX2( 0, 0.,  99., 0., 1.49E4, 44, A38+1, A66+1, A65+1, -JTEST, A37+1,      08/30/73.  NEW
     .        A63+1)$                                                               08/30/73.  NEW
      PLEND                                                                         08/30/73.  NEW
      END                                                                           08/30/73.  NEW
      BCD 3VARIABLES 1                                                              08/30/73.  NEW
C     INSERT CONSUMABLES CAPACITY ADJUSTMENT                                        08/30/73.  NEW
      C40= 214. + (1- TIMEN/TIMEND) * 524.                                          08/30/73.  NEW
      IF ( TIMEN.LT.8.2 .OR. TIMEN .GT. 8.3)GO TO 5                                 08/30/73.  NEW
      DO 15 I=1,15                                                                  08/30/73.  NEW
      A100+I=0.                                                                     08/30/73.  NEW
15    A101+I=0.                                                                     08/30/73.  NEW
5     DO 10 I=1, 15                                                                 08/30/73.  NEW
        Q1+I-1=(A100+I*R3+A101+I*R4)*11.12                                          08/30/73.  NEW
       Q39=Q39 + (A100+I * R3 + A101+I * R4)*8.70                                   08/30/73.  NEW
       Q40+I-1 = (A100+I * R3 + A101+I * R4)*6.14                                   08/30/73.  NEW
10    Q58+I-1 = (A100+I * R1 + A101+I * R2)*2.49                                    08/30/73.  NEW
      Q176=Q137=13.*72.* R7                                                         08/30/73.  NEW
      Q79=2750. $ AVIONICS HEAT DISSIPATION                                         08/30/73.  NEW
      Q119DA(TIMEN, A102, A103, .37, C82)                                           08/30/73.  NEW
      Q114DA(TIMEN, A102, A104, .7, C81)                                            08/30/73.  NEW
      END                                                                           08/30/73.  NEW
      BCD 3VARIABLES 2                                                              08/30/73.  NEW
      END                                                                           08/30/73.  NEW
      BCD 3OUTPUT CALLS                                                             08/30/73.  NEW
      TPRINT                                                                        08/30/73.  NEW
      JTEST=JTEST+1                                                                 08/30/73.  NEW
      A 2 + JTEST = T18                                                             08/30/73.  NEW
      A 4 + JTEST = T57                                                             08/30/73.  NEW
      A 5 + JTEST = T75                                                             08/30/73.  NEW
      A 6 + JTEST = T 9                                                             08/30/73.  NEW
```

```
A 8 + JTEST = T48                                             247     08/30/73.   NEW
A 9 + JTEST = T66                                             248     08/30/73.   NEW
A10 + JTEST = T 5                                             249     08/30/73.   NEW
A12 + JTEST = T44                                             250     08/30/73.   NEW
A13 + JTEST = T62                                             251     08/30/73.   NEW
A14 + JTEST = T14                                             252     08/30/73.   NEW
A16 + JTEST = T53                                             253     08/30/73.   NEW
A17 + JTEST = T71                                             254     08/30/73.   NEW
A18 + JTEST = T38                                             255     08/30/73.   NEW
A19 + JTEST = T39                                             256     08/30/73.   NEW
A20 + JTEST = T77                                             257     08/30/73.   NEW
A21 + JTEST = T73                                             258     08/30/73.   NEW
A22 + JTEST = T37                                             259     08/30/73.   NEW
A23 + JTEST = T76                                             260     08/30/73.   NEW
A24 + JTEST = T81                                             261     08/30/73.   NEW
A25 + JTEST = T82                                             262     08/30/73.   NEW
A37 + JTEST = TIMEN                                           263     08/30/73.   NEW
A52 + JTEST = T137                                            264     08/30/73.   NEW
A53 + JTEST = T176                                            265     08/30/73.   NEW
A59 + JTEST = T79                                             266     08/30/73.   NEW
A60 + JTEST = T80                                             267     08/30/73.   NEW
A61 + JTEST = C80                                             268     08/30/73.   NEW
A62 + JTEST = C81                                             269     08/30/73.   NEW
A63 + JTEST = C82                                             270     08/30/73.   NEW
END                                                           271     08/30/73.   NEW
300 3END OF DATA                                              272     08/30/73.   NEW

INITIAL CONDITIONS HAVE BEEN STORED ON TAPE 22, SO RESTART OF INITIAL CONDITIONS CAN BE PERFORMED.
 THE RESTART NAME IS ST0000
```

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APPENDIX D

REMOTE MANNED SYSTEM VISUAL DOCKING CONTROL EVALUATION

REMOTE MANNED SYSTEM VISUAL DOCKING CONTROL EVALUATION

The effects of transmission delays, control modes and visual aids on Tug docking (300 feet to contact) controlled manually from a ground based station were evaluated using the MMC Space Operations Simulation Facility. The simulation technique (Figure D-1) utilizes a 6 degree-of-freedom servodriven, moving base simulator to generate the relative dynamic conditions between a Tug vehicle and a target. A television camera mounted on the moving-base gimbal system viewed a target at the end of the simulator room. A pilot observed the simulated docking scene on a monitor at a control console (Figure D-2) located in an adjacent room. Range and range-rate were displayed on an adjacent monitor.

The pilot determined his closure corrections by observing, relative to a reticle on the television monitor, the target motion at longer ranges and the docking visual-aid motion at closer ranges. Apollo rotational and translational controllers were used to generate Tug vehicle commands. Servo commands for the moving base simulator were computed using the Tug vehicle commands as inputs to a math model of the problem dynamics. Relative motion between the Tug vehicle and the target was simulated in this manner.

The simulation was conducted in two phases: Phase I Static Alignment and Phase II Dynamic Docking.

Phase I - Static Alignment

The objective of the static alignment phase was to determine the pilot's ability to determine the closure guidance errors as a function of: range to target, transmission delays, and visual aids (3 types). At a series of designated ranges the pilot performed stationkeeping maneuvers while aligning the Tug vehicle as accurately as possible to the docking axes of the target using the docking visual aid. Three visual aids were investigated: a standard Apollo type standoff "tee", a large Apollo "tee" (twice the standard "tee" size) and an Apollo/Soyuz standoff "box". During these runs the pilot used rate control in both translation and rotation. The effect of a five-second video delay was also investigated. Control loop limit cycle and fuel slosh effects were not included.

The docking alignment errors (vertical, lateral, pitch, yaw and roll) as a function of range are shown in Figure D-3 thru D-7. The results shown that the Apollo docking requirements are readily met at the contact point for all the visual aids investigated - even with video delay. For attitude, the alignment errors were within the 10 degree Apollo docking values from within 100 feet. For lateral and vertical alignment, the errors were within the 1-foot Apollo docking value from about 60 feet on in for the worst case. This data shows that the visual aids investigated provide more than adequate sensitivity for guidance error determination under the conditions investigated. Also, the video delay did not create appreciable degradation. However, the pilots did utilize more time to perform the stationkeeping maneuvers with the 5 second video delay.

Phase II Dynamic Docking

The objective of the dynamic docking phase was to measure the pilot's ability to perform the docking maneuver as a function of: translation control mode (acceleration and rate) and transmission delays (5 second video and 2.4 second range and range-rate). In this phase the pilot performed the closure maneuver in a manner similar to that used on Apollo. He was instructed to maintain a range-rate profile of +0.5 ft/sec. ± 0.2 ft/sec. The docking terminal conditions plus maneuver times, are shown in Table D-1. Apollo docking requirements are also shown for comparison purposes. The Apollo docking requirements were met for all runs. However, time and operator work-load did increase significantly when the 5 second video delay was introduced. It was concluded, for the translation acceleration mode with delay, that the Apollo-type closure profile was not acceptable. The pilot's performance was too marginal - even though the terminal conditions were not greater than for other runs. When the pilots were allowed to perform a standoff maneuver at about 20 feet, they could readily keep the docking maneuver under control. The conclusions of the study are summarized in Table D-2.

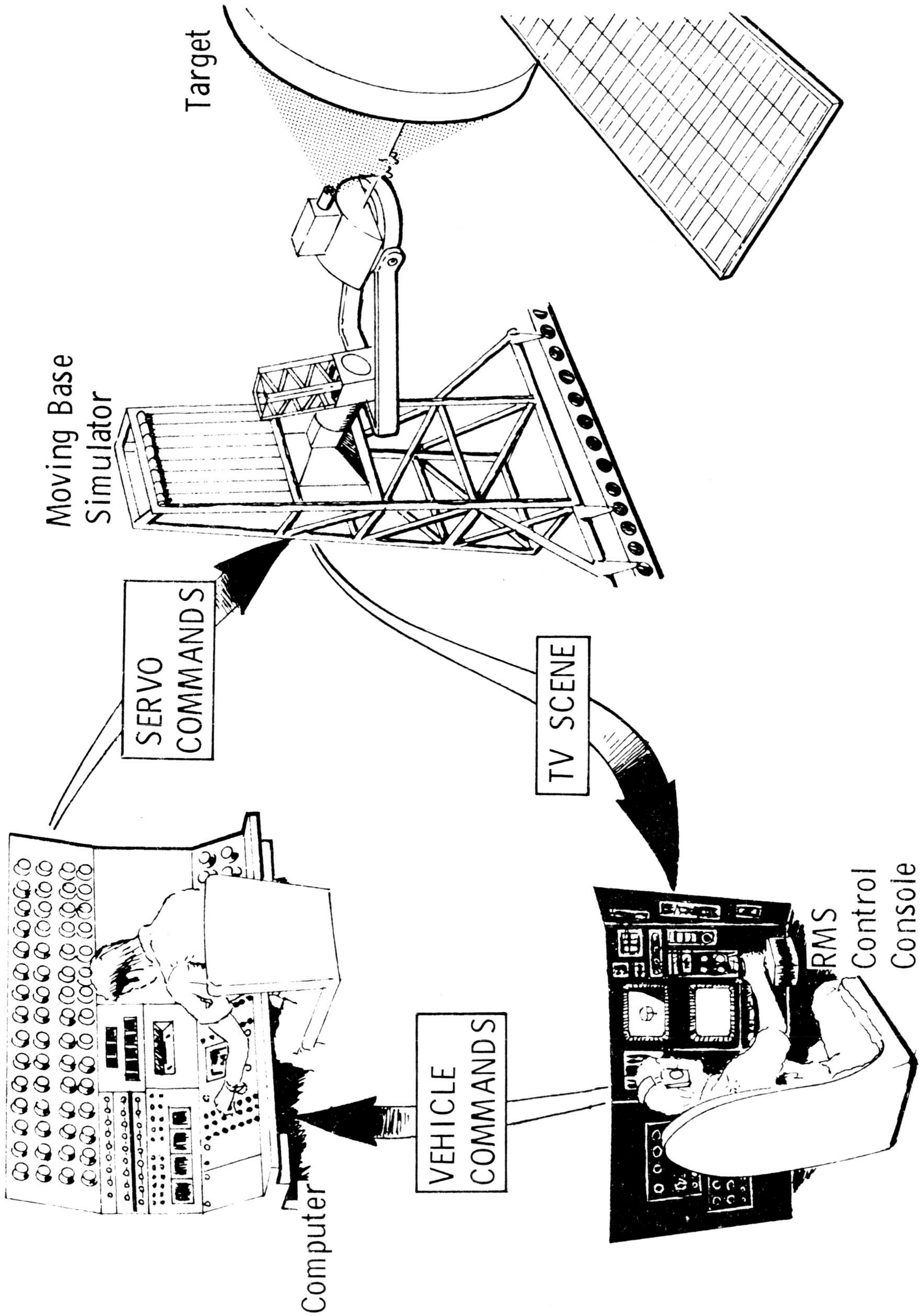

FIGURE D-1 REMOTE MANNED SYSTEM SIMULATION

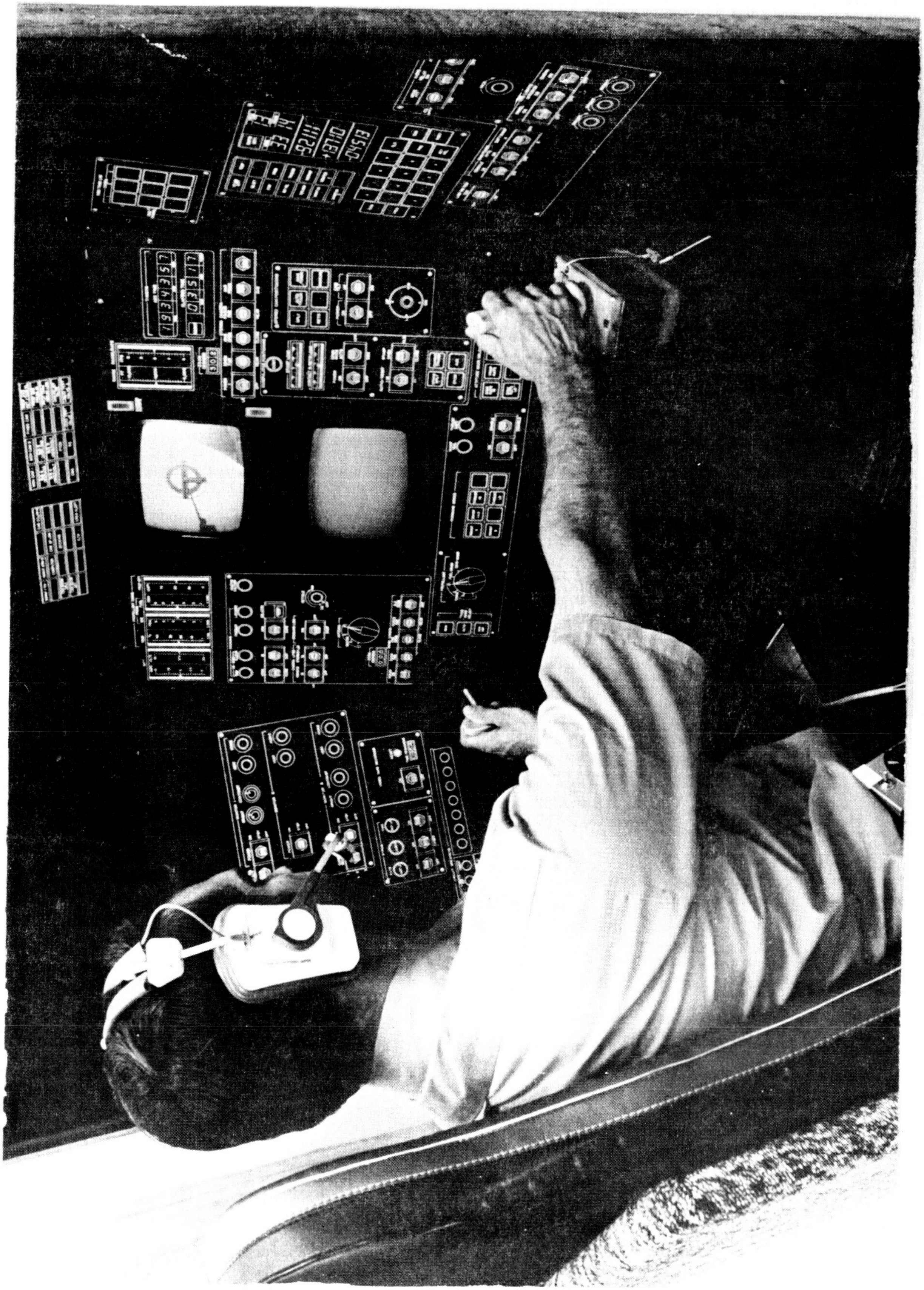

Figure D-2 Control Console

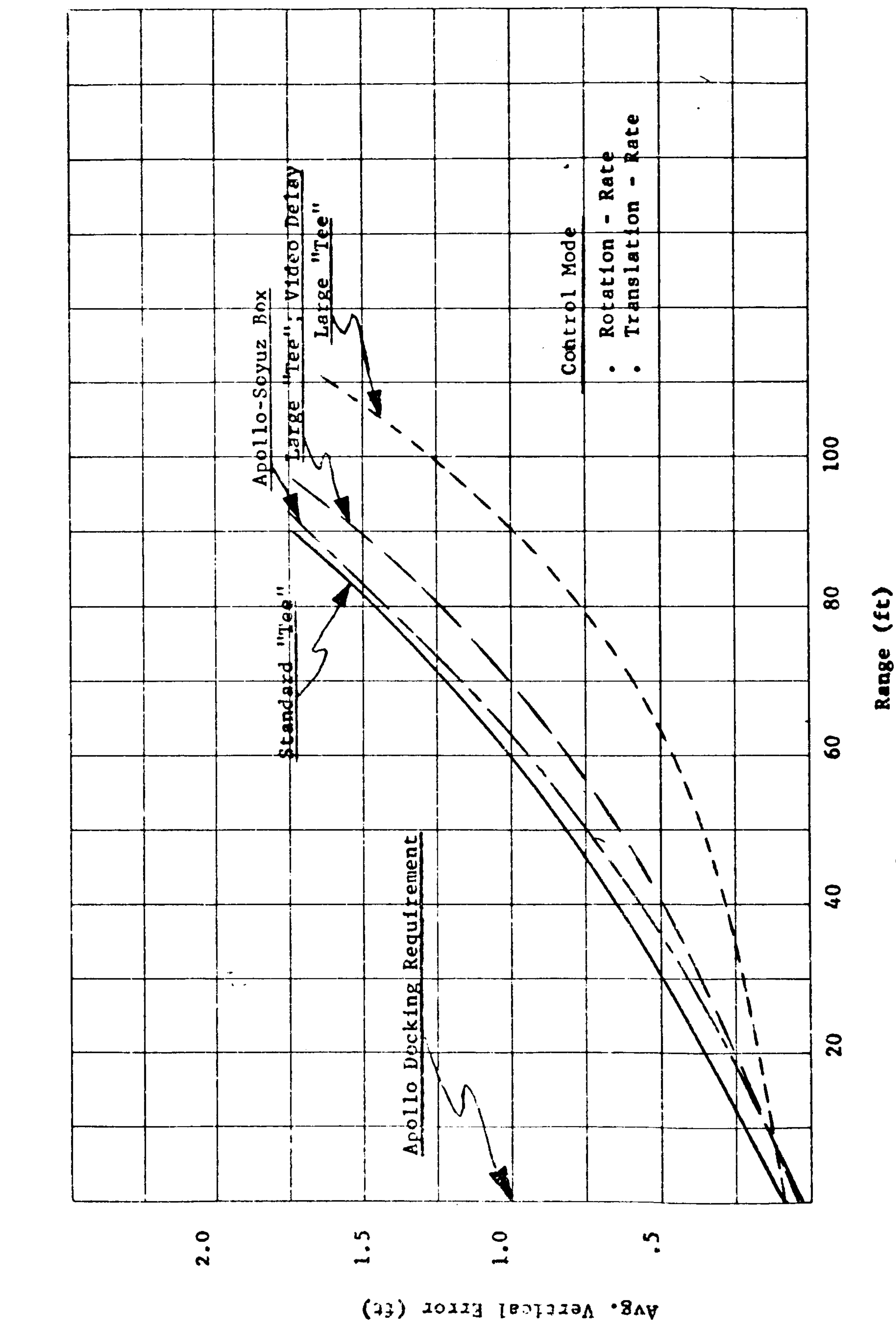

FIGURE D-3 VERTICAL ALIGNMENT ERROR

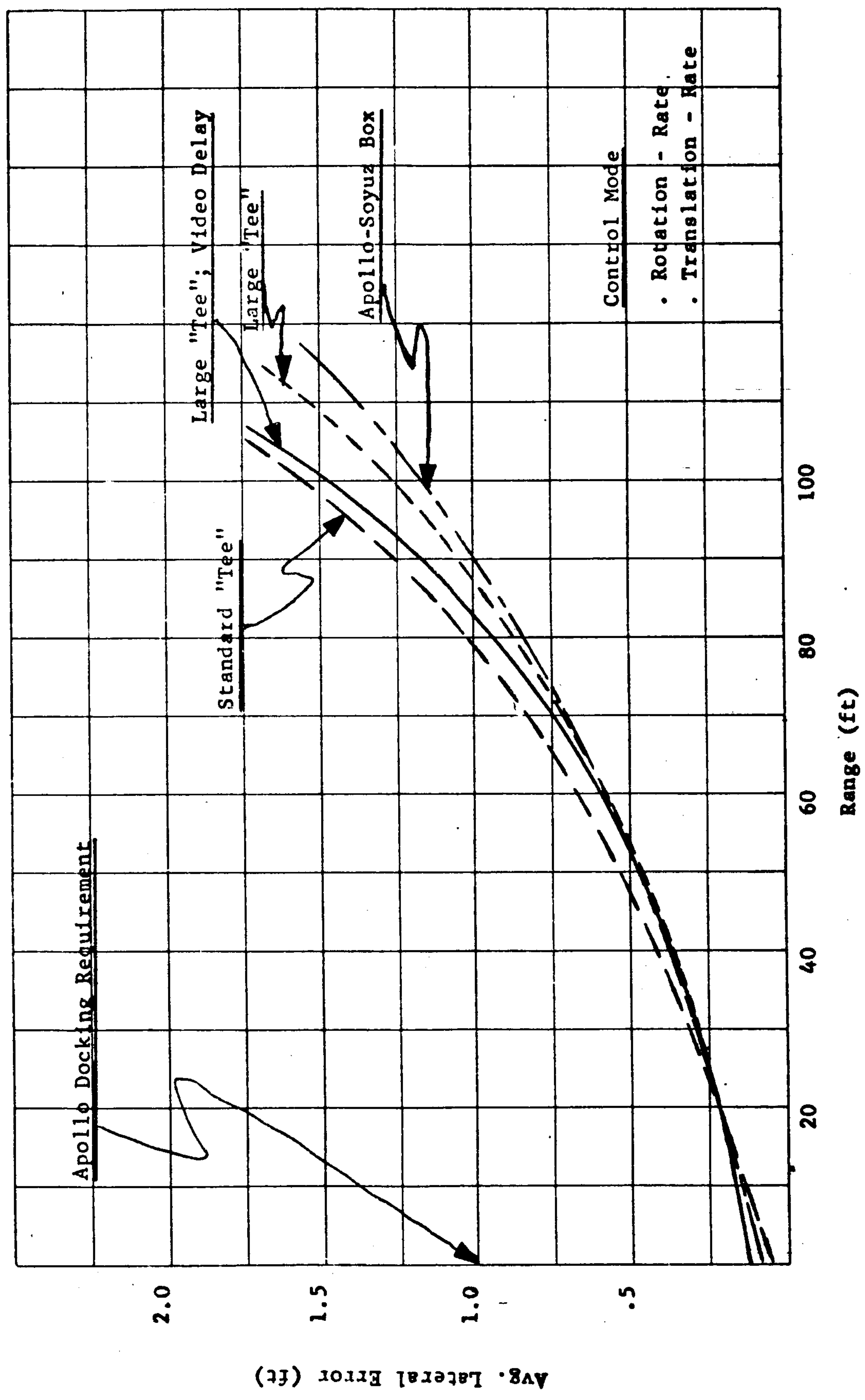

FIGURE D-4 LATERAL ALIGNMENT ERROR

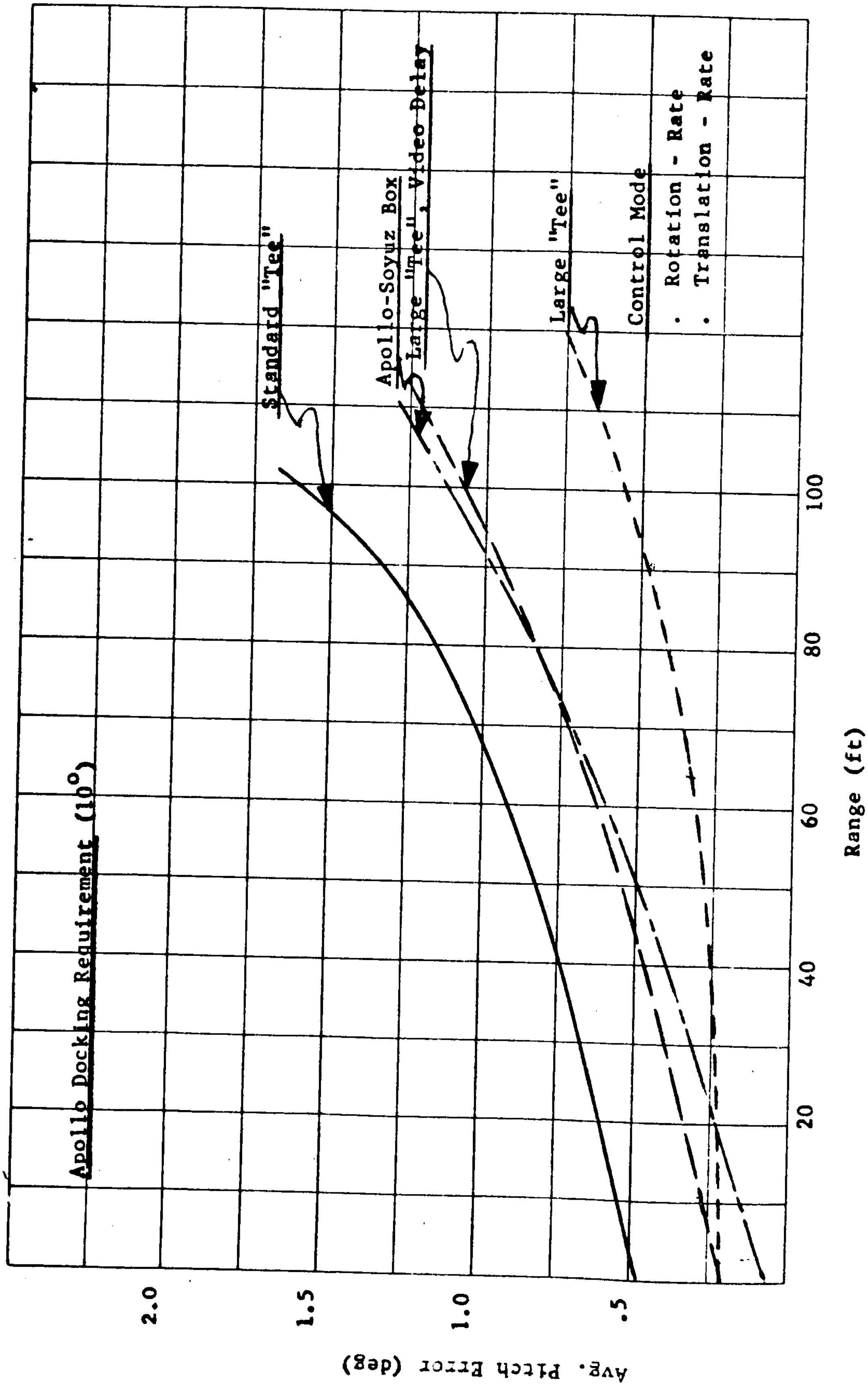

FIGURE D-5 PITCH ALIGNMENT ERROR

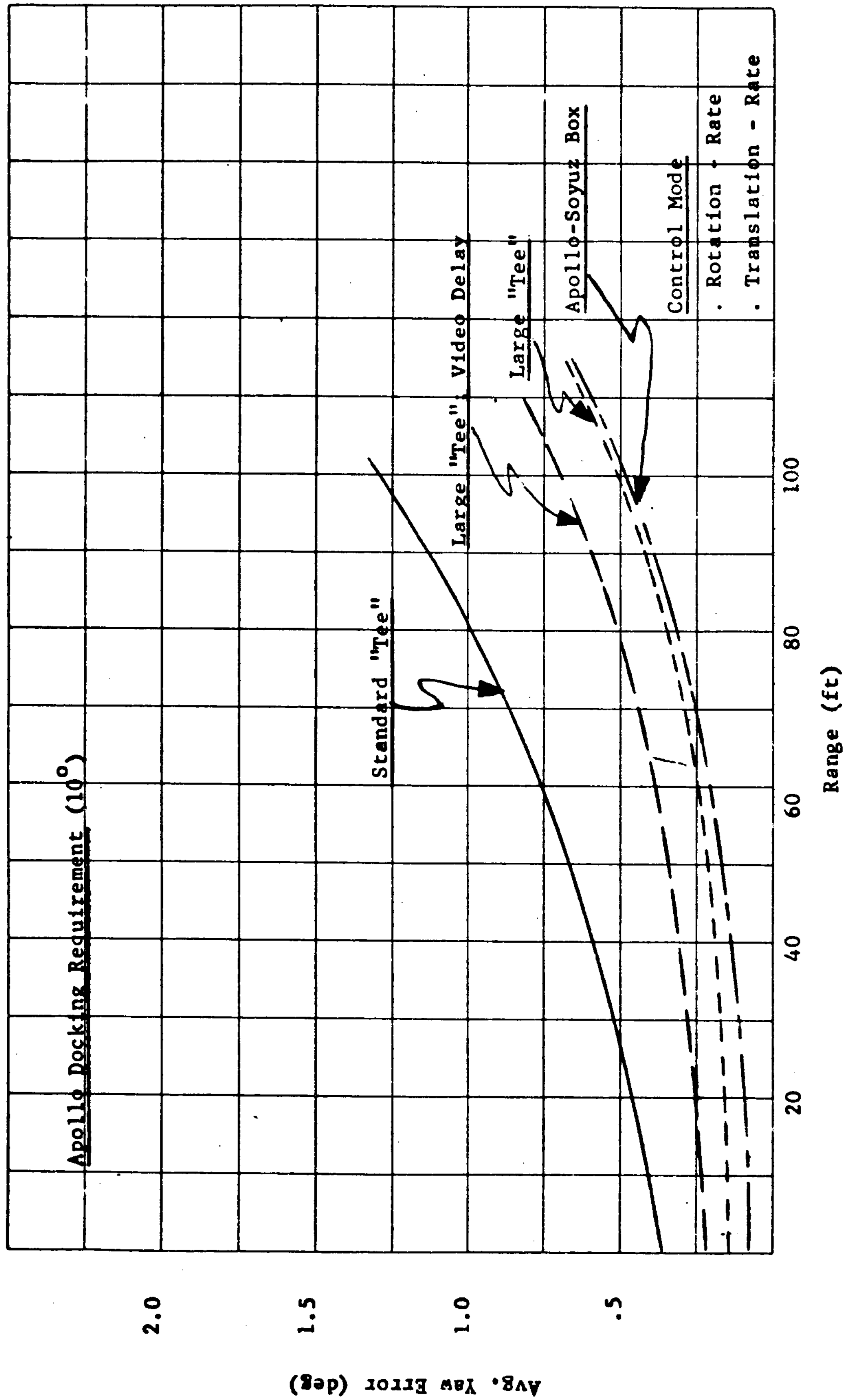

FIGURE D-6 YAW ALIGNMENT ERROR

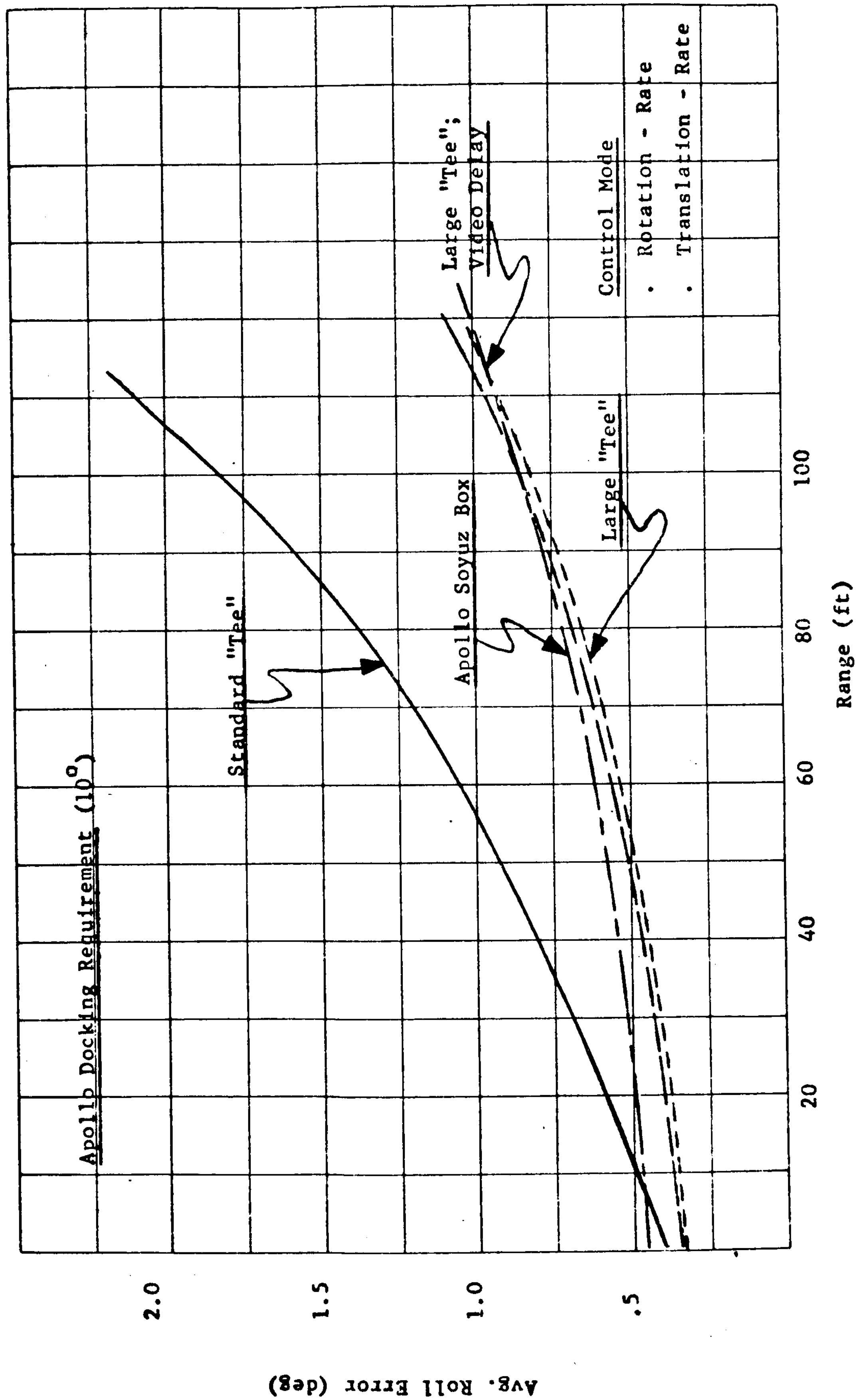

FIGURE D-7 ROLL ALIGNMENT ERROR

TABLE D-1 DOCKING TERMINAL CONDITIONS

TRANS. MODE		DELAY		ATTITUDE ERRORS			TRANSLATIONAL ERRORS						TIME
RATE	ACCEL.	VIDEO (5 SEC)	$\dot{R}$&R (2.4 sec)	Θ deg	ψ deg	ϕ deg	$\dot{X}$ ft/sec	Y ft	$\dot{Y}$ ft/sec	Z ft	$\dot{Z}$ ft/sec	TIME min
X				0.2	0.3	0.3	0.4	0.1	0	0.1	0	3.9
X		X		1.6	1.4	0.6	0.4	0.4	0	0.2	0	4.6
X		X	X	0.4	0.3	1.1	0.4	0.3	0	0.2	0	4.4
	X			2.0	0.8	0.5	0.4	0.2	0.1	0.2	0.2	6.3
	X	X		1.3	0.3	0.4	0.4	0.3	0.1	0.4	0.1	9.2
	X	X	X	0.2	0.8	1.6	0.4	0.2	0	0.3	0.1	8.4
APOLLO REQUIREMENTS				± 10	± 10	± 10	$.5 \pm .2$	1.0	0.5	1.0	0.5	-

- **Visual Aid: Large "Tee"**
- **Rotational Mode: Rate**

TABLE D-2 CONCLUSIONS OF SIMULATION

TRANS. MODE		DELAY		SIMULATION PHASES	
RATE	ACCEL.	VIDEO	R&R	PHASE I STATIC ALIGNMENT	PHASE II DYNAMIC DOCKING
X				Readily Performed	Readily Performed
	X			Readily Performed Time & work-load greater than for Rate Mode.	Readily Performed
X		X		Adequately Performed Time & work-load greater than for Accel. Mode.	Adequately Performed
X		X	X	———	Little change from Rates Mode with Video Delay
	X	X		———	Difficult to complete. Requires a standoff maneuver. Time & work-load increase.
	X	X	X	———	Little change from Accel. Mode with Video Delay.

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APPENDIX E

SPACE TUG STUDY

COMPUTER REDUNDANCY MANAGEMENT

15 August 1973

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CONTENTS

I. SUMMARY

A redundancy scheme tentatively selected for the current configuration of the Space Tug avionics is a dual redundant concept called "pilot/copilot". Experience with this concept at Martin Marietta has found it efficient and workable. Detailed tradeoffs have not yet been conducted on the tug avionics, therefore the final selection of the redundancy management method could well change as detailed studies evolve. Until that stage in design the pilot/copilot method will be considered baseline. The discussion presented here will be limited to that. This concept utilizes two computers, both on and each performing identical computations, however, only one has its output enabled. The other is comparing the computations of each via software. A diagnostic is initiated when the comparison check fails. This diagnostic is essentially a self check of both computers. Dependent on the outcome of that self test, control may or may not be transferred. The delay in recovery from a failure is the length of that self test which can be anywhere from 10 to 600 ms depending on the complexity of the self test. Studies have shown that the effectiveness achieved in finding failures with a self test can be better than 99%. A major advantage of the pilot/copilot scheme is that only two rather than 3 computers need be on to achieve nearly the same immunity to failures that Triple-Majority-Vote provides.

A penalty in this concept is the additional software required to provide the cross check comparisons of the computers' computations and the self test. This penalty depends on how often the cross check is made and at what level of computation it is made, i.e., at many intermediate steps in a computation or once at the end of a computation. The latter is more desirable as it is less complex and less time consuming. The preliminary nature of the avionics systems of the Tug makes finite estimates of the software impact difficult. However, examination of other programs utilizing pilot/copilot redundancy management technology indicate that the total memory requirements should not exceed 2200 words and the amount of the computation time per cycle should be something less than 300 μsec for this application.

The hardware impact of this concept is minimal. No specialized hardware is required. The reconfiguration after failure is done at the output by straight forward power switching.

II. DISCUSSION

A. General

The present configuration of the Space Tug Avionics System employs a central computer system. This system incorporates redundancy at the module level, i.e., processor, memory, and I/O. For purposes of explanation the system may be represented as in Figure 1. The discussion that follows will describe the redundancy management approach of that configuration and rationale for its selection. It is recognized that the preliminary state of the tug configuration will undoubtedly result in many changes to the avionics as time goes by and consequently to its redundancy management concept. The concept, therefore, is detailed and at times explicit, not for the purpose of conveying a sense of finality to the selection but rather to allow for an introduction and discussion of other alternatives and options that may not be applicable now but should be considered as the avionics configuration evolves.

The computer subsystem, as depicted in Figure 1, is composed of three general processors (GP), four memories, and 2 CDTC's (command, data, timing and checkout), the latter being the I/O to the data busses. The CDTC also has computational or processor capability, performing limit checks on subsystems, etc. Only one CDTC is normally on and the other powered down. Of the three processors, two are on and the third may be off. These two operating processors and a memory associated with each are working in what will be referred to hereafter as a pilot/copilot mode.

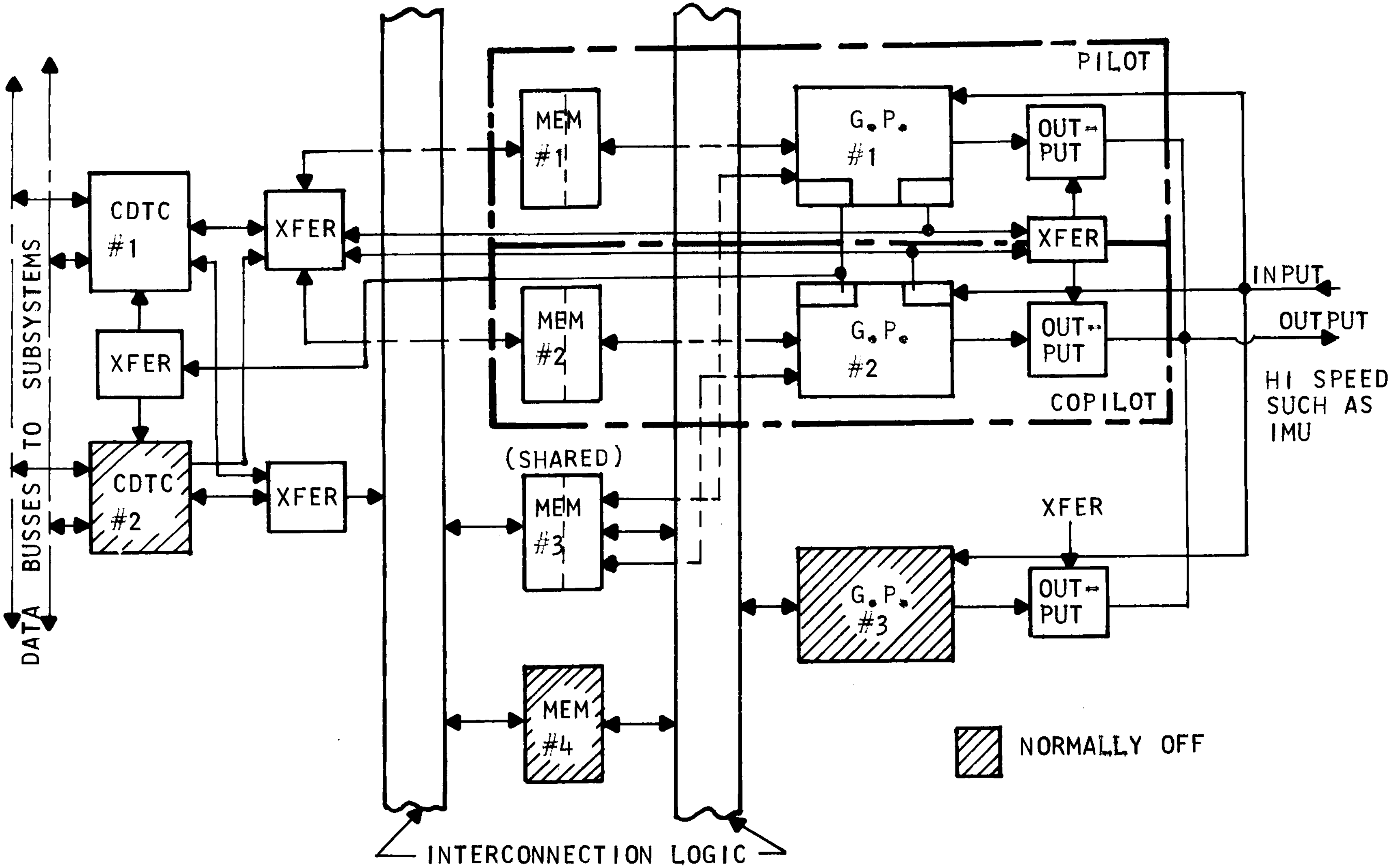

FIGURE 1. COMPUTER CONFIGURATION

NOTE: THE MODULE INTERCONNECTIONS SHOWN DOTTED THROUGH THE INTERCONNECTION LOGIC ARE THOSE FOR NORMAL PILOT/COPILOT MODE OF OPERATION. ADDITIONAL RECONFIGURATION MAY BE PROVIDED BY GROUND OR ON-BOARD, DEPENDING ON COMPLEXITY OF INTERCONNECTION LOGIC.

One processor and memory is in control. The other is performing identical computation and checking the pilot but is not in control until a failure is indicated. This is a redundancy management scheme conceived and patented* at Martin Marietta with a view toward applying it to digital flight control systems. It is the core of the redundancy management approach for the tug computer configuration and is discussed in detail later. Some of the features considered in selection of this scheme are:

1. The occurrence of a failure in the operating unit will result in a very minimal recovery delay (10-600 ms depending on the depth of the self check employed). This is opposed to a passive redundancy configuration which has a more formidable problem in starting and initializing a redundant dormant computer after a failure.
2. It uses less power than Triple Majority Vote configurations.
3. Alleviates the need for error detection codes, parity checks, or reinitalization process.
4. Software for both computers may be identical.

The pilot and copilot processors can be thought of as each having a dedicated memory. This affords some protection against cross contamination from the other processor's memory failures. This configuration does not preclude a third memory being on and shared by both processors, if desired. The third memory provides a focal point for pilot/copilot cross communication if desired and can also provide additional storage capability, particularly for non-critical computations.

The CDTC will normally share the pilots' memory. When control is transferred from the pilot to copilot the CDTC memory access is transferred to the copilot memory. Included in the checking and cross checking process of the redundancy management concept

*Gary Lovell and Tom E. Conover: Redundant Computer System, Patent No. 3,444,528, issued May 13, 1969.

is the identification of any CDTC, as well as GP/memory, failures. Discrimination between the two will be necessary such that a faulty CDTC can be shut down and its backup switched in onboard.

The checking function of the redundancy management scheme is shown in the processor on Figure 1. It could, however, be provided in the memories if more efficient.

Another important facet of an overall redundancy management concept is that concerned with management of the redundant data buses and subsystems. There will be software in the avionics computer system, particularly the CDTC, for this function, however, its details depend considerably on the subsystems and their requirements rather than the computer configuration itself. The relative independence of the key requirements for these two parts of the overall concept allow for this discussion to be limited to the computer system redundancy management without introducing any gross inaccuracies.

Once a failure has been detected and the copilot computer has completed the mission phase successfully, either onboard logic, or the ground, will reconfigure the entire system such that the normal pilot/copilot operation is again established using the remaining operable modules.

B. Pilot/Copilot Features

The search for improved reliability has led to the development of the pilot/copilot concept for those systems where power constraints disallow computer majority voting. The pilot/copilot configuration offers significant reliability and fault tolerance for minimum power requirements.

The pilot/copilot concept falls within the more general class of parellel processing where two computers perform the same computational task in synchronism, with the outputs compared for equality. The distinguishing features of the pilot/copilot system are:

1. Computer cross checks perform the data comparison and fault detection task.
2. Self tests identify the malfunctioning computer string.
3. Reconfiguration after a fault is accomplished by selecting the remaining operative computer string.

Cross checks consist of each computer monitoring the other's I/O outputs. Also, cumulative status tables are compiled and cross checked at the end of, and possibly during, each computational cycle. Self tests are entered after cross check failure and consistsof program check sums, functional diagnostics, and I/O wrap-around checks. Reconfiguration is based on the outcome of self tests, and is achieved by giving control to the remaining operative string.

The pilot/copilot configuration may be reduced to single string operation by simply de-powering one computer: no significant hardware changes are required. This could be a low power back-up mode, or a ground commanded fall-back mode should the pilot/copilot fail to recover after a fault.

Typical Pilot/Copilot System Description - Figure 2 illustrated the basic system configuration, consisting of two digital computers and their corresponding input and output units. Note that the system outputs are fed back into the input units and that cross communication exists between the two computers. The cross communication may be in the form of hardware intercommunication registers, or shared memory. One system has been arbitrarily designated pilot and the other copilot. Aside from minor programming differences due to cross checking, these two systems are identical and perform the same processing task simultaneously. However, only one will be providing the actual output at any given time.

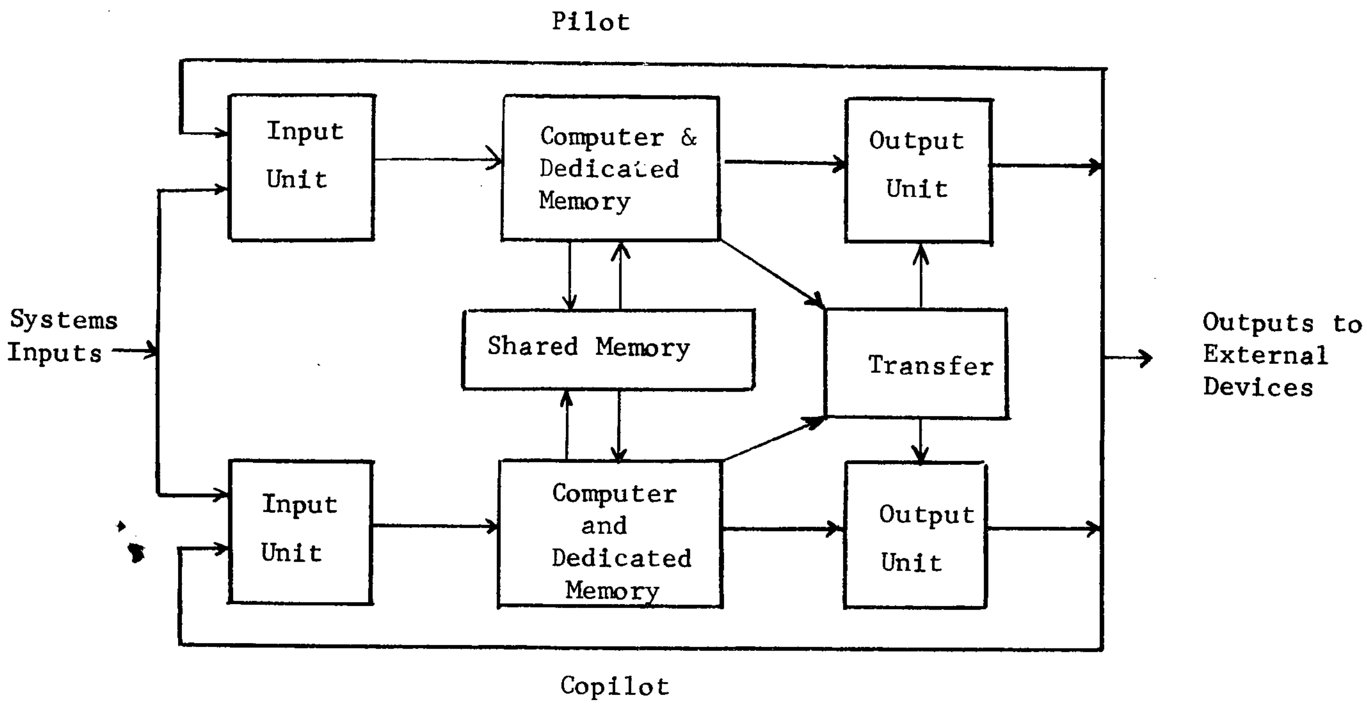

FIGURE 2. TYPICAL DUAL REDUNDANT CONFIGURATION

Under normal operating conditions, the pilot computer has complete control with the copilot performing only a monitoring and cross-check function. Both the pilot and copilot accept the same inputs, process the data in the same manner, and when both are functioning properly, generate the same corresponding outputs.

Cross Checks - In greater detail, the normal cross checking sequence is as follows:

1. The copilot computer resets the pilot's status word while the pilot computer resets the copilot's status word at the commencement of a computational cycle.
2. During the computational phase, at certain key points, segments of the pilot's status word will be set by the pilot if the proper criteria have been met. Similarly, corresponding segments of the copilot's status word will be set by the copilot.
3. At the end of the computational phase, a cross check is

made on these status words, and also on the computational output. Actions are taken according to Table 1, and self test may be initiated on discompare.

The above action places the computers in the position of being assumed inoperative unless they can prove otherwise, and as both computers have been processing in synchronism, recovery problems are minimal. The only delay has been the time required for self test.

The cross check is variable in extent, and depends on system tradeoffs against control loop timing. The status table may be only a few words long, or in the limit could mirror an entire memory. One rather large dual system (CAGE), developed at Martin Marietta for TIIIM, described at the 1968 Fall Joint Computer conference required 320 micro-seconds for cross check servicing. The frequency of cross check is also variable, and may be performed once or many times per control loop cycle.

Flow charts typical of the cross check function in this redundancy management technique are provided for a pilot and copilot computer in Figures 3 and 4. They are representative of the design in the Lovell, Conover patent. It is unlikely the same flow would suit the tug application since the cross checks will be dictated to a great extent by the tug requirements.

Reliability - The reliability of the pilot/copilot system is dependent on the effectiveness of self test to the extent that with perfect self test (zero probability of a failure not being identified by self tests) the pilot/copilot reliability can rival that of the triple majority vote system. In order to compare the two systems, a graph showing their theoretical reliability ratios as a function of single string mission reliability and the probability that a pilot failure is detectable is shown in Figure 5. From this figure it is evident that detectability of pilot failure (primarily self test) is the dominate parameter for highly reliable systems, and because of imperfect detectability,

TABLE 1: CROSS CHECK COMPARISONS

FAILURE TYPE	RESULT
Pilot cross check status vector in illegal state or never set	Copilot detects that pilot status vector has remained reset and initiates self test mode.
Copilot cross check status vector in illegal state or never set	Pilot detects that copilot status vector has remained reset and initiates self test mode and recovery
Both pilot and copilot status vectors in illegal state or never set	Possible only with multiple failures, self test will be initiated
Pilot and copilot status tables or output commands not equal at end of computation cycle.	Indicates computer problem or I/O unit failure. Both computers enter I/O wrap-around tests and self test in attempt to isolate problem and recover with workable configuration.
Pilot output command and status vector equals copilot output command and status vector	This is normal operating mode and processing continues without self test.

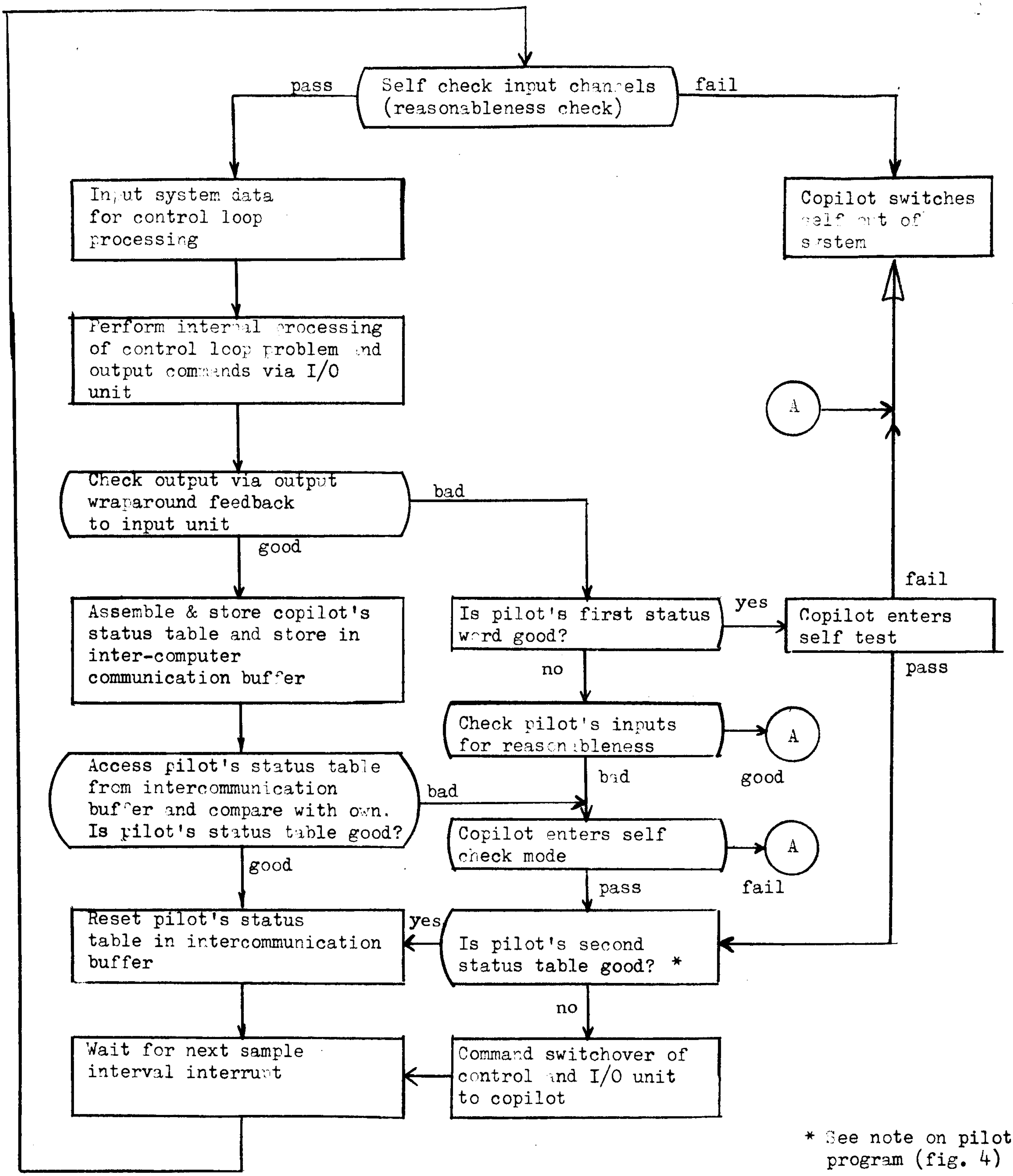

Figure 3: Copilot program block diagram

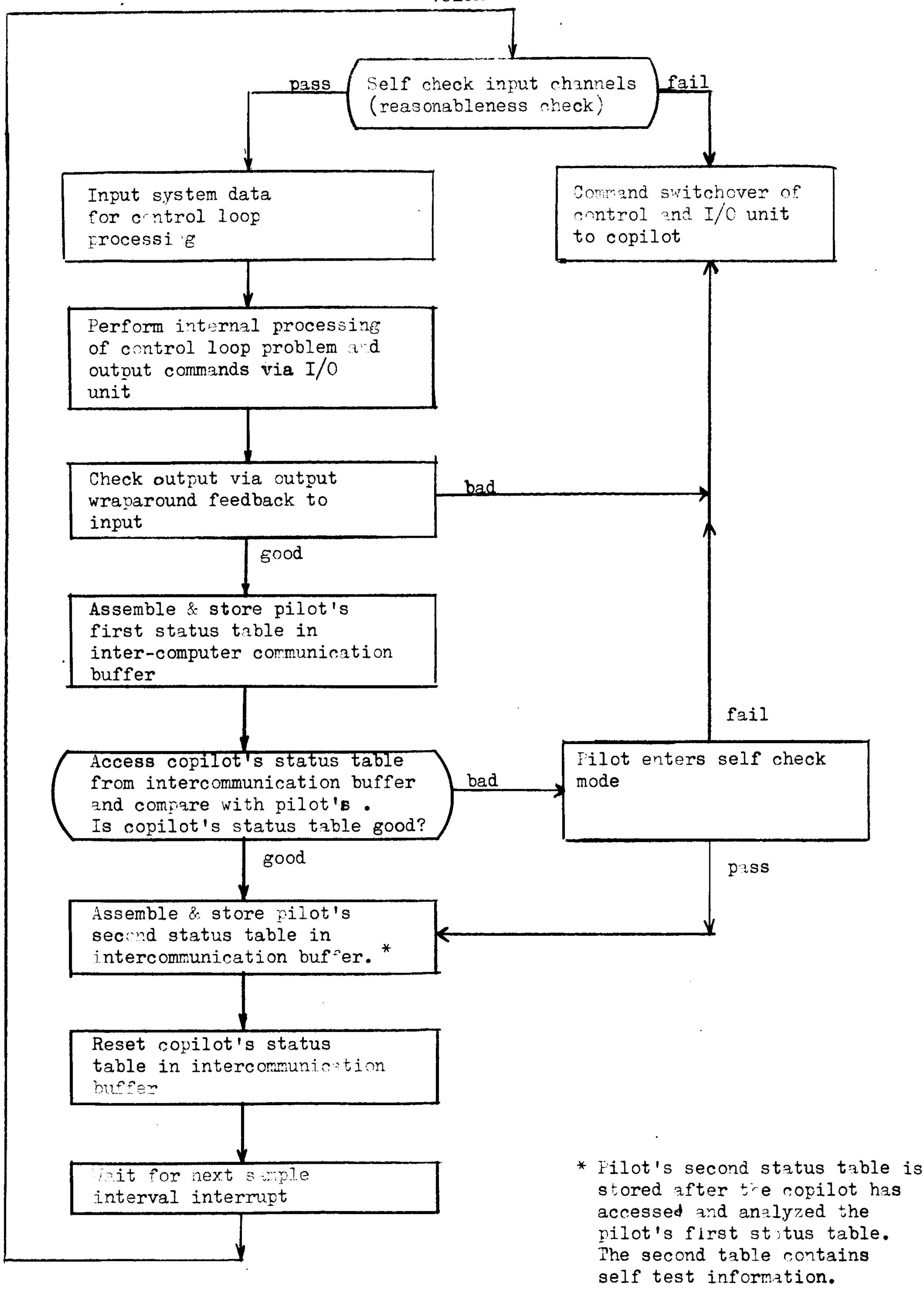

Figure 4: Pilot program block diagram

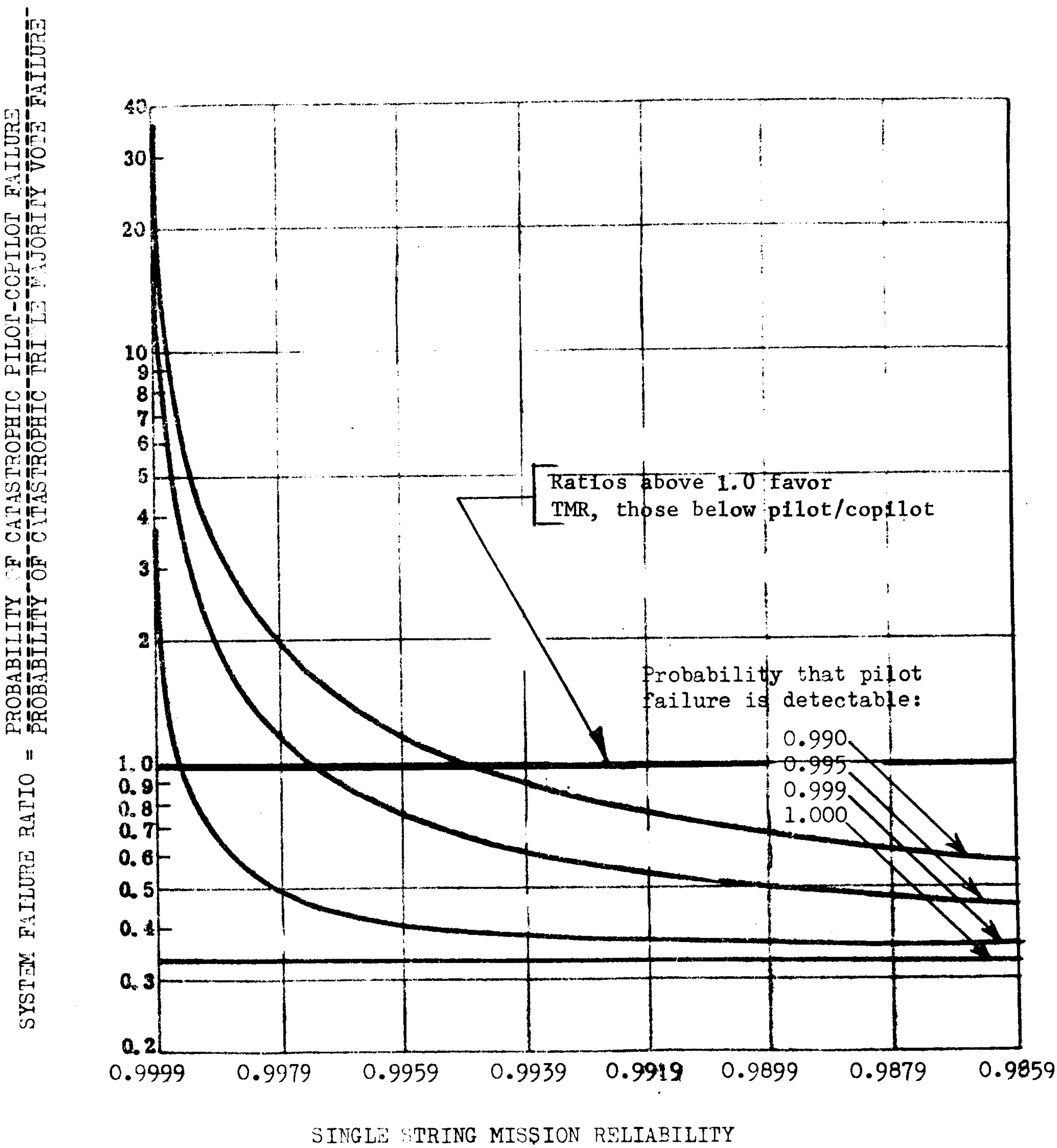

Figure 5: Pilot-copilot and triple majority vote failure ratio comparison

pilot/copilot is better suited for those users where the mission reliability of a single string is less than 0.995. The single string mission reliability for space tug candidates is estimated at .983. Please refer to reference 1 in the bibliography for a more detailed reliability analysis.

Self Test Survey - Three study contracts were awarded to three computer manufacturers (Autonetics, GE, Univac) for the purpose of determining the optimum methods of self test and test confidence data.

The self checks recommended were 3: check-sum of program storage memory, functional self check of instruction repertoire, and, a sentry time (employed in one instance). Each of the contractors computed an effectiveness of better than 99%, as the probability of detecting any error that might occur in his respective processor. The self check execution times and storage requirements are as follows:

1. Functional test - 7 ms maximum execution time, 500 words program storage. (The Viking Lander self test program grew to 1000 words storage).
2. Program check-sum - 13 words storage for check-sum program, 100 ms execution time per 4000 words checked.

Software and Hardware Requirements Summary - The pilot/copilot redundancy management concept relies primarily on software rather than hardware. There is really no specialized hardware required to perform redundancy management, such as the voters in TMR. There is hardware involved, of course, in transferring output from pilot to copilot but this is straight forward power switching, as is transfer of control from CDTC #1 to #2. The major impact then lies in the software area. It can be considered in two parts. The first is the software impact of the cross check feature and secondly, the self test. Software is defined here as the additional memory required and the effect on the cycle times performing the redundancy management test.

Since overall design of the avionics and its computer system is so preliminary credible numbers are virtually impossible to come by. Discussion of other programs that utilized similar techniques may provide some perspective on these requirements. In a survey of several vendors on the subject of self test schemes, as discussed earlier, it was found the estimates of storage required ranged from 329 to 466 words. In the Viking Lander computer design, which employed a self test feature, it was found that the storage required actually approached 1000 words. The time to complete the self check may vary from just a few milli-seconds to 500 or 600 ms depending on the depth of the check. For the pilot/copilot scheme this is not really a penalty on normal computation cycle time because the self check is not employed until a discompare occurs.

The cross check requirement is more intangible than the self check at this time as it is much more dependent on the actual magnitude and nature of the tasks the computer will perform. One data point is the relatively complex ground check-out system discussed in reference 6. This is a dual processor (Scientific Data Systems Sigma 7's) scheme employing a version of pilot/copilot redundancy management. The core required to perform the total dual processing control and error detection was 1200 words. The time to perform that cross check was 320 microseconds.

Based on these few data points a very preliminary estimate for the total concept's memory requirement is something less than 2200 words and time penalty is less than 320 μs.

III. EXPERIENCE RESOURCES

The span of Martin Marietta's experience in computer system organizations ranges from the conceptual approaches developed under a fault-tolerance study described to the practical experience of implementing fault tolerance and redundancy in a contractual hardware program such as the Viking lander. Other systems are discussed, including in-place facilities, flight hardware, and ground support equipment. We have developed software to support all of these systems to satisfy both contractual and corporation requirements.

Computerized Aerospace Ground Equipment (CAGE)(AF04(695-997) - CAGE is a data monitoring checkout and launch control system originally designed for the Titan III MOL Program. During launch control, two processors act in a dual-redundant mode, both processors receiving and evaluating all data from the launch vehicle. The system consists of two XDS Sigma 7 I/O. The CAGE software is extensive. Self-test is initiated if disagreement between the two CPUs is encountered. It was found that extensive additions to the on-line operating system software were required to cope with synchronizing and controlling the dual processors.

GCSC Viking Lander (Contract NAS1-9000) - Martin Marietta is currently procuring the Viking lander guidance control and sequencing computer (GCSC) from Honeywell, Inc. In arriving at the current design a number of redundancy studies and the Viking mission risk criteria forced the addition of considerable redundancy to the flight control system. The lander computer is block redundant (passive). Each computer has a variety of interesting features specifically included for fault-tolerance considerations.

The computer requirements demanded that at least 95% of all hardware faults be detectable by a self-test program; a 97 to 99% detection coverage has been achieved. The computer design was considerably influenced by this self-test requirement; for instance, an internal I/O register wraparound technique was necessary to test the I/O, which comprises approximately half of the computer hardware.

Computer error detection hardware was specified to prevent propagation of transient errors in a noisy environment and to provide for immediate instruction retry in the event of illegal address, illegal operation code, or memory parity. I/O parity errors also lead to retry under software control. A voltage out-of-tolerance interrupt is accumulated for memory readout as a general implication of health history.

An active dual-redundant system was also considered. Because the critical mission phase of descent is relatively short and because lock-step, compare, and wait operations for error detection were considered technically risky, this concept was rejected. However, the detailed analyses of both configuration and enhancement concepts for the design provide a wealth of documented pertinent results.

Fault-Tolerant Digital Systems Study - Martin Marietta continuing interest in fault-tolerant aerospace digital systems is reflected in this IR&D task. Initiated in 1970, topics ranging from theoretical configurations and coverage to specific fail-safe circuit designs have been tested.

This study evaluated the effect that existing fault-tolerant systems and technologies have on cost effective aerospace data systems. Two systems (JPL's STAR and the Bell Telephone ESS) were described and compared. A reliable command link and fail-safe logic techniques were described. Requirements for control and conditioning logic were defined. An appendix includes examples of reliable logic, memory, and power switching implementations.

Another valuable output of this task was Fault-Tolerant Computing Technology Handbook. The object was to accumulate diverse experience that could be quickly reviewed and exploited. The following information is included for each technique: level of detail (system, component), application, description (verbal, flow chart, mathematical, diagram), quantitative cost parameters, limitations/constraints, specific capabilities, and pointers to pertinent references.

Dual-Redundant (Pilot/Copilot) Computer Concept - Martin Marietta has designed and patented a dual-redundant computer concept. It employs two complete processing systems, both active, to provide a functional system. Under normal operation, one computer, called the pilot, has complete control, with the other, called the copilot, performing only a monitoring or cross-check function. Both the pilot and copilot accept the same inputs, process the data in the same manner and, when both are functioning properly, generate the same outputs. When the copilot monitoring and cross-check function determines a malfunction, control is passed to the copilot. The software and hardware developed for this function will be of benefit in performing this study.

Redundant Aerospace Integrated Data Systems (RAIDS) - This is a dual-redundant system, developed in an IR&D task, that performs the functions required for guidance, navigation, flight control, telemetry data acquisition, malfunction detection, checkout, and launch control for a launch vehicle. The system allows for single, nonconcurrent failures in any subsystem without degradation of the mission. Sun sensor and actuator subsystems are triply redundant with majority vote.

Autopilot Design and Computer Sizing Study (NAS12-2048) - Analysis and design of the Titan III digital autopilot gains and filters needed for vehicle stabilization led to a comprehensive description of the software mechanism, including timing, sizing, and I/O requirements.

Titan III Digital Autopilot (AF04(695)-150) - The Titan IIIC autopilot software includes a set of malfunction-detection logic that can identify errors and initiate corrective action. Path errors are detected and corrected by loop-check logic. The calculation and storage errors are detected and corrected by reasonability checks. If either the engine command checks or the vehicle motion checks are failed, the logic has the capability to ignore one-time-only transients. Within 1 to 2 seconds the vehicle will recover from any transient induced by a calculation error and the resulting initialization process. The overall malfunction logic requires 446 instructions and parameters, which is about 8% of the total memory requirements.

Redundant Data Bus Systems (NAS8-27538) - A prototype quad-redundant data terminal allows the system to meet the fail-operational, fail-safe criterion required by the Space Shuttle.

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